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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Underwater acoustics – Hydrophones – Calibration of hydrophones – Part 2: Procedures for low frequency pressure calibration

Acoustique sous-marine – Hydrophones – Étalonnage des hydrophones – Partie 2: Procédures pour l'étalonnage à basse pression de fréquence

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UNDERWATER ACOUSTICS – HYDROPHONES – CALIBRATION OF HYDROPHONES –

Part 2: Procedures for low frequency pressure calibration

FOREWORD

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International Standard IEC 60565-2 has been prepared by IEC technical committee 87: Ultrasonics.

This first edition of IEC 60565-2, together with IEC 60565-1, replaces the second edition of IEC 60565 published in 2006. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition.

1) IEC 60565 has been divided into two parts:
   - Part 1: Procedures for free-field calibration;
   - Part 2: Procedures for low frequency pressure calibration (this document).
2) A relative calibration method has been added to Clause 8: Calibration by piezoelectric compensation.

3) A relative calibration method has been added to Clause 11: Calibration by **vibrating column**.
4) Clause 12: Calibration by static pressure transducer, has been added.
5) Annex A: Equivalent circuit of the excitation system for calibration with a **vibrating column**, has been deleted.
6) Subclauses 9.6, 9.7 and 9.8 have been moved to form a new Annex A: Advanced acoustic coupler calibration methods.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
87/720/FDIS	87/723/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

NOTE Words in **bold** in the text are terms defined in Clause 3.

A list of all parts in the IEC 60565 series, published under the general title *Underwater acoustics – Hydrophones – Calibration of hydrophones*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://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.

INTRODUCTION

The purpose of this document is to establish the procedures for low frequency pressure calibrations of **hydrophone**s in the frequency range from 0,01 Hz to several kilohertz.

To ensure the correctness of the calibrations, the **hydrophone**s to be calibrated are "rigid" **hydrophone**s with small size compared to the acoustic wavelength, and are not sensitive to vibration when calibrated.

Principles, procedures, and **uncertainties** of physical calibrations such as hydrostatic excitation, piezoelectric compensation, **pistonphone**, **vibrating column**, static pressure transducer, etc., and reciprocity calibrations in acoustic **coupler**s are given in this document. Calibrations are carried out using one of these methods, depending on the different principles to be used, and its limitations to the sound field and the frequency range.

UNDERWATER ACOUSTICS – HYDROPHONES – CALIBRATION OF HYDROPHONES –

Part 2: Procedures for low frequency pressure calibration

1 Scope

This part of IEC 60565 specifies the methods for low frequency pressure calibration of **hydrophone**s at frequencies from 0,01 Hz to several kilohertz depending on calibration method.

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 60050-801, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics* (available at http://www.electropedia.org/)

IEC 60500:2017, *Underwater acoustics – Hydrophones – Properties of the hydrophone in the frequency range 1 Hz to 500 kHz*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-801, IEC 60500:2017 and the following apply.

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

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

3.1
coupler
apparatus comprising a rigid fluid-filled chamber into which transducers and **hydrophone**s can be inserted whose largest dimension is small compared to the wavelength

Note 1 to entry: In this document, the term small chamber is used interchangeably with **coupler**.

[SOURCE: IEC 60565:2006 [1][1], 3.3, modified – In the definition, "small dimensions" has been replaced by "whose largest dimension is small compared to the wavelength".]

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

3.2
diffraction factor
ratio of the root-mean-square value of the sound pressure, averaged over the part of the **hydrophone** designed to receive an incident plane wave sound pressure from a given direction to the free-field root-mean-square sound pressure that would exist at the position of the reference centre of the **hydrophone** if the **hydrophone** was removed

Note 1 to entry: Spatial average is undertaken first and then time average.

[SOURCE: IEC 60500:2017, 3.3, modified – In the definition, "the root-mean-square sound pressure" has been replaced by "the root-mean-square value of the sound pressure,", and "the position of" has been added after "that would exist at".]

3.3
electrical transfer impedance
$\underline{Z}_{PH}$
<of a transducer pair in a coupler> quotient of the Fourier transform of the open circuit voltage $\Im(U_H(t))$ across the **hydrophone** electrical terminals, to the Fourier transform of the electrical current $\Im(I_P(t))$ through the **projector**, when **projector** and **hydrophone** are mounted in a **coupler**

$$\underline{Z}_{PH} = \frac{\Im(U_H(t))}{\Im(I_P(t))} \tag{1}$$

Note 1 to entry: The **electrical transfer impedance** is a complex-valued parameter. The modulus of the **electrical transfer impedance** is expressed in ohm, Ω. The phase angle is expressed in degrees, and represents the phase difference between the **hydrophone** voltage and the **projector** current.

Note 2 to entry: Because the **electrical transfer impedance** depends on the field conditions, the hydrostatic pressure, water temperature and the length of the cable attached to the transducer, these parameters, as well as the frequency and the electrical terminals where the electrical impedance is measured, are specified.

[SOURCE: IEC 60565:2006 [1], 3.10, modified – In the term, "transducer pair" has been deleted. The domain "<of a transducer pair in a coupler>" has been added. In the definition, "complex ratio of the open circuit instantaneous voltage U_H" has been replaced by "quotient of the Fourier transform of the open circuit voltage $\Im(U_H(t))$", "the instantaneous current I_P" has been replaced by "Fourier transform of the electrical current $\Im(I_P(t))$", and "if **projector** and **hydrophone** are mounted in a free field with their principal axes in line and directed towards each other" has been replaced by "when **projector** and **hydrophone** are mounted in a **coupler**".]

3.4
hydrophone
electroacoustic transducer that produces electrical voltages in response to water borne pressure **signal**s

Note 1 to entry: A **hydrophone** is designed to respond principally to underwater sound pressure.

Note 2 to entry: In general, a **hydrophone** can also produce a **signal** in response to non-acoustic pressure fluctuations (for example, those existing in a turbulent boundary layer during conditions of high water flow).

Note 3 to entry: **Hydrophone** types include reference **hydrophone**s and measuring **hydrophone**s. Measuring **hydrophone**s are used in general measurements of sound fields, and reference **hydrophone**s are principally used for calibration purposes (for example in comparison calibrations with measuring **hydrophone**s).

Note 4 to entry: **Hydrophone**s are principally used as listening devices, but in reciprocity calibration, a **hydrophone** is used as **reciprocal transducer**, not only acting as a **hydrophone**, but also as a **projector** (sound source).

Note 5 to entry: A **hydrophone** which is integrated with a digital acquisition system is sometimes termed a "digital **hydrophone**", but the combination is best considered as a measuring system, not a **hydrophone** alone.

Note 6 to entry: If a **hydrophone** is connected to a charge amplifier, the sensitivity of the **hydrophone** is sometimes described in terms of charge sensitivity, which is related to the voltage sensitivity of the **hydrophone** by its electrical capacitance.

[SOURCE: IEC 60500:2017, 3.17, modified – In the definition, "electrical **signal**s" has been replaced by "electrical voltages".]

3.5
pistonphone
apparatus having a rigid piston which can be given a reciprocating motion of a known frequency and amplitude to establish a known sound pressure in a closed small chamber

[SOURCE: IEC 60565:2006 [1], 3.20, modified – In the definition, "so permitting the establishment of" has been replaced by "to establish", and "a closed chamber of small dimensions" by "a closed small chamber".]

3.6
pressure sensitivity
$\underline{M}_\mathrm{p}$
<of a **hydrophone**> quotient of the Fourier transform of the **hydrophone** open-circuit voltage **signal** $\Im(U_\mathrm{H}(t))$ to the Fourier transform of the acoustic pressure **signal** $\Im(p(t))$ averaged over the **hydrophone** active element, at a specified frequency

$$\underline{M}_\mathrm{p} = \frac{\Im\left(U_\mathrm{H}(t)\right)}{\Im\left(p(t)\right)} \qquad (2)$$

Note 1 to entry: The **hydrophone pressure sensitivity** is a complex-valued parameter. The modulus of the **pressure sensitivity** of a **hydrophone** is expressed in units of volt per pascal, V/Pa. The phase angle of the sensitivity is expressed in degrees, and represents the phase difference between the electrical voltage and the sound pressure.

Note 2 to entry: The term "response" is sometimes used instead of "sensitivity".

Note 3 to entry: The **hydrophone** active element is the electroacoustic element of the **hydrophone** which is sensitive to sound pressure.

[SOURCE: IEC 60500:2017, 3.23, modified – In the definition, "ratio of the root-mean-square output voltage" has been replaced by "quotient of the Fourier transform of the **hydrophone** open-circuit output voltage **signal** $\Im(U_\mathrm{H}(t))$", and "root-mean-square of the sound pressure" has been replaced by "Fourier transform of the sound pressure $\Im(p(t))$".The description of the **hydrophone** active element has been moved to a Note to entry.]

3.7
pressure sensitivity level
L_M
twenty times the logarithm to the base 10 of the ratio of the modulus of the **pressure sensitivity** $\left|\underline{M}_\mathrm{p}\right|$ to a reference sensitivity of M_ref, in decibels

$$L_\mathrm{M} = 20 \log_{10} \frac{\left|\underline{M}_\mathrm{p}\right|}{M_\mathrm{ref}} \ \mathrm{dB} \qquad (3)$$

Note 1 to entry: The value of reference sensitivity M_ref is 1 V/µPa.

[SOURCE: IEC 60500:2017, 3.24, modified – In the definition, "modulus of the" has been added before "**pressure sensitivity**", and "in decibels" has been added after "M_ref".]

3.8
projector
electro-acoustic transducer that converts electric **signal**s into sound **signal**s propagating in water

[SOURCE: IEC 60565:2006 [1], 3.37]

3.9
ratio of specific heats
γ
ratio of specific heats under constant pressure and under constant volume

Note 1 to entry: For dry air and temperature 0 °C to 17 °C, γ = 1,40.

3.10
reciprocal transducer
linear, passive, and reversible electroacoustic transducer such that the coupling coefficients are equal for transduction in either direction

[SOURCE: IEC 60565:2006 [1], 3.24, modified – In the definition, "transducer" has been replaced by "electroacoustic transducer", and "such that the coupling coefficients are equal for transduction in either direction" has been added at the end of the definition.]

3.11
signal

specified time-varying electric current, voltage, sound pressure, sound particle displacement, or other field quantity of interest

[SOURCE: ISO 18405:2017 [2], 3.1.5.8]

3.12
transmitting response to current
$\underline{S}_{\mathrm{I,T}}$
<of a transducer in a coupler> quotient of the Fourier transform of the acoustic pressure **signal** $\Im(p(t))$ to the Fourier transform of the electrical current **signal** $\Im(I(t))$ through a transducer T inserted into the **coupler** at a given frequency

$$\underline{S}_{\mathrm{I,T}} = \frac{\Im(p(t))}{\Im(I(t))} \tag{4}$$

Note 1 to entry: **Transmitting response to current** is expressed in units of pascal per ampere, Pa/A.

Note 2 to entry: Different with the free-field calibration, no distance term is required here.

Note 3 to entry: The acoustic pressure signal is assumed uniform in a **coupler**.

[SOURCE: IEC 60565:2006 [1], 3.36, modified – In the term, "small chamber transmitting response to current of a transducer" has been replaced by "**transmitting response to current**". The domain "<of a transducer in a coupler>" has been added. In the definition, "a small chamber" has been replaced by "a **coupler**", and "flowing through the electrical terminals of a transducer inside the chamber" by "through a transducer inserted into the **coupler**". Also, "current" has been replaced by "Fourier transform of the electrical current **signal** $\Im(U_{\mathrm{H}}(t))$", and "ratio of the acoustical pressure (assumed uniform)" has been replaced by "quotient of the Fourier transform of the acoustic pressure signal $\Im(p(t))$".]

3.13
uncertainty
<of measurement> non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

[SOURCE: ISO/IEC Guide 99:2007 [3], 2.26]

3.14
vibrating column
apparatus in which a column of water in a vertically placed cylindrical container is set in vibration, causing a depth-dependent sound pressure in the water column

Note 1 to entry: The length of the column is sufficiently small compared with the wavelength of the sound in the water. The cross-sectional dimension of the column is small compared with its length.

[SOURCE: IEC 60565:2006 [1], 3.38]

3.15
wavenumber
k
reciprocal of the acoustic wavelength multiplied by 2π

$$k = 2\pi / \lambda \tag{5}$$

Note 1 to entry: **Wavenumber** is expressed in units of per metre, m^{-1}.

Note 2 to entry: In different branches of physics, the term **wavenumber** can be considered equal to either $2\pi/\lambda$ or $1/\lambda$, but in the technical field of acoustics, $2\pi/\lambda$ is preferred. This term given in IEC 60050-103:2009, 103-10-12 is "angular **wavenumber**".

[SOURCE: IEC 60050-726:1982 [4], 726-05-02, modified – In the definition, "the reciprocal of the waveguide wavelength or the" and "for a plane wave" have been deleted, and "acoustic" and "multiplied by 2π" have been added before and after "wavelength", respectively.]

4 Symbols

C_t acoustic compliance of chamber

C_M compliance of the medium

c speed of sound in water

c_f speed of sound in a fluid

d depth or distance of the **hydrophone**

d_{jk} piezoelectric modulus of the shell material

E Young's modulus

f frequency

g acceleration due to gravity

h displacement of the water surface in the open vessel

H_e equivalent height

ΔH change of the water level

I_P current through **projector**

I_T current through transducer

I_c compensation current through null **projector**

K characteristic constant of piezoelectric null transducer

K_0	hydrostatic pressure correction factor
k	**wavenumber**
L	length of column or **coupler**
L_M	**pressure sensitivity level** of the **hydrophone**
M_H	sensitivity of the **hydrophone**
M_p	**pressure sensitivity**
M_T	sensitivity of the static pressure transducer
M_M	sensitivity of the microphone
p	sound pressure
p_s	static pressure
Q	mechanical quality factor
r	radius of transducer shell
S_P	**transmitting response to current** of a **projector** in a **coupler**
S_T	**transmitting response to current** of a transducer in a **coupler**
U_C	compensation voltage
U_H	open-circuit voltage at **hydrophone**
U_M	open-circuit voltage at microphone
U_{PH}	open-circuit voltage at **hydrophone** with a **projector** as sound source
U_{PT}	open-circuit voltage at transducer with a **projector** as sound source
U_{TH}	open-circuit voltage at **hydrophone** with a transducer as sound source
U_R	open-circuit voltage at a reference **hydrophone**
$\underline{u}$	volume velocity
V_b	volume of the subsidiary body
V_t	total volume
ΔV	volume change
x_0	vibration amplitude
Z	contains all the terms involving transfer impedance
$\underline{Z}_{AI}$	acoustic impedance
$\underline{Z}_{PH}$	**electrical transfer impedance** of **projector** and **hydrophone** in a **coupler**
$\underline{Z}_{PT}$	**electrical transfer impedance** of **projector** and transducer in a **coupler**
$\underline{Z}_{TH}$	**electrical transfer impedance** of transducer and **hydrophone** in a **coupler**
$\underline{Z}_{TP}$	**electrical transfer impedance** of transducer to **projector** in a **coupler**
γ	**ratio of specific heats**
ρ	density of water
ρ_f	density of fluid
σ	Poisson's modulus
ω	angular frequency
ω_r	resonance angular frequency

5 Procedures for calibration

5.1 Principles

a) Absolute calibration