BS EN 62127-2:2007+A2:2017

BSI Standards Publication

Ultrasonics – Hydrophones

Part 2: Calibration for ultrasonic fields up to 40 MHz (IEC 62127-2:2007)

bsi.

National foreword

This British Standard is the UK implementation of EN 62127-2:2007, incorporating amendment A1:2013 and including amendment A2:2017. It is identical to IEC 62127-2:2007, incorporating amendment 1:2013 and including amendment 2:2017. It supersedes BS EN 62127-2:2007+A1:2013, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment A1 is indicated by A1⟩ ⟨A1.

The text of IEC amendment 2:2017 has been provided in its entirety at the beginning of this document. BSI's policy of providing consolidated content remains unchanged; however, in the interest of expediency, in this instance BSI have chosen to collate the relevant content at the beginning of this document.

The UK participation in its preparation was entrusted to Technical Committee EPL/87, Ultrasonics.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2018

ISBN 978 0 580 91813 1

ICS 17.140.50

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 May 2008.

Amendments/corrigenda issued since publication

Date	Text affected
31 July 2013	Implementation of IEC amendment 1:2013 with CENELEC endorsement A1:2013: Annex ZA updated
31 March 2018	Implementation of IEC amendment 2:2017 with CENELEC endorsement A2:2017

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 62127-2

October 2007

ICS 17.140.50

Partially supersedes EN 61101:1993, EN 61102:1993 + A1:1994, EN 61220:1995 and EN 62092:2001

English version

Ultrasonics - Hydrophones - Part 2: Calibration for ultrasonic fields up to 40 MHz
(IEC 62127-2:2007)

Ultrasons -
Hydrophones -
Partie 2: Etalonnage pour les champs ultrasonores jusqu'à 40 Mhz
(CEI 62127-2:2007)

Ultraschall -
Hydrophone -
Teil 2: Kalibrierung für Ultraschallfelder bis zu 40 MHz
(IEC 62127-2:2007)

This European Standard was approved by CENELEC on 2007-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization

Comité Européen de Normalisation Electrotechnique

Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 87/353/CDV, future edition 1 of IEC 62127-2, prepared by IEC TC 87, Ultrasonics, was submitted to the IEC-CENELEC parallel Unique Acceptance Procedure and was approved by CENELEC as EN 62127-2 on 2007-09-01.

EN 62127-1, EN 62127-2 and EN 62127-3 are being published simultaneously. Together these European Standards cancel and replace EN 61101:1993, EN 61102:1993 + A1:1994, EN 61220:1995 and EN 62092:2001.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2008-06-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2010-09-01

Annex ZA has been added by CENELEC.

____

Endorsement notice

The text of the International Standard IEC 62127-2:2007 was approved by CENELEC as a European Standard without any modification.

____

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 62127-2/A1

March 2013

ICS 11.040.50

English version

Ultrasonics - Hydrophones - Part 2: Calibration for ultrasonic fields up to 40 MHz
(IEC 62127-2:2007/A1:2013)

Ultrasons - Hydrophones -
Partie 2: Etalonnage des champs ultrasoniques jusqu'à 40 Mhz
(CEI 62127-2:2007/A1:2013)

Ultraschall - Hydrophone -
Teil 2: Kalibrierung für Ultraschallfelder bis zu 40 MHz
(IEC 62127-2:2007/A1:2013)

This amendment A1 modifies the European Standard EN 62127-2:2007; it was approved by CENELEC on 2013-03-15. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this amendment the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This amendment exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Management Centre: Avenue Marnix 17, B - 1000 Brussels

Foreword

The text of document 87/519/FDIS, future amendment 1 to edition 1 of IEC 62127-2, prepared by IEC/TC 87 "Ultrasonics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62127-2:2007/A1:2013.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-12-15
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-03-15

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 62127-2:2007/A1:2013 was approved by CENELEC as a European Standard without any modification.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 62127-2:2007/A2

June 2017

ICS 17.140.50

English Version

Ultrasonics - Hydrophones - Part 2: Calibration for ultrasonic fields up to 40 MHz (IEC 62127-2:2007/A2:2017)

Ultrasons - Hydrophones - Partie 2: Etalonnage des champs ultrasoniques jusqu'à 40 Mhz (IEC 62127-2:2007/A2:2017)

Ultraschall - Hydrophone - Teil 2: Kalibrierung für Ultraschallfelder bis zu 40 MHz (IEC 62127-2:2007/A2:2017)

This amendment A2 modifies the European Standard EN 62127-2:2007; it was approved by CENELEC on 2017-04-26. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this amendment the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This amendment exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 62127-2:2007/A2:2017 E

European foreword

The text of document 87/612/CDV, future IEC 62127-2:2007/A2, prepared by IEC/TC 87 "Ultrasonics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62127-2:2007/A2:2017.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2018-01-26
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2020-04-26

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 62127-2:2007/A2:2017 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-801	-	International Electrotechnical Vocabulary (IEV) - Chapter 801: Acoustics and electroacoustics	-	-
IEC 60565	-[1)]	Underwater acoustics - Hydrophones - Calibration in the frequency range 0,01 Hz to 1 MHz	EN 60565	2007[2)]
IEC 61161	-	Ultrasonics - Power measurement - Radiation force balances and performance requirements	EN 61161	-
IEC 61689	-	Ultrasonics - Physiotherapy systems - Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz	EN 61689	-
IEC 61828	-	Ultrasonics - Focusing transducers - Definitions and measurement methods for the transmitted fields	EN 61828	-
IEC 62127-1 + corr. August + A1	2007 2008 2013	Ultrasonics - Hydrophones - Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz	EN 62127-1 + A1	2007 2013
IEC 62127-3	-[1)]	Ultrasonics - Hydrophones - Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz	EN 62127-3	2007[2)]

IEC 62127-2

Edition 1.0 2017-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

AMENDMENT 2
AMENDEMENT 2

Ultrasonics – Hydrophones –
Part 2: Calibration for ultrasonic fields up to 40 MHz

Ultrasons – Hydrophones –
Partie 2: Etalonnage des champs ultrasoniques jusqu'à 40 MHz

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.140.50

ISBN 978-2-8322-3904-9

FOREWORD

This amendment has been prepared by IEC technical committee 87: Ultrasonics.

The text of this amendment is based on the following documents:

CDV	Report on voting
87/612/CDV	87/639/RVC

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

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

---

2 Normative references

Add the following new reference:

IEC 61689, *Ultrasonics – Physiotherapy systems – Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz*

3 Terms, definitions and symbols

3.26
derived instantaneous intensity

(added by Amendment 1)

Delete the following text below the term:

"approximation of the **instantaneous intensity**"

Replace the existing four lines before Equation (1) by the following:

quotient of squared instantaneous acoustic pressure and characteristic acoustic impedance of the medium at a particular instant in time at a particular point in an acoustic field

4 List of symbols

Replace:

ρc specific acoustic impedance

by

ρc characteristic acoustic impedance of the measurement liquid (water)

Add the following new symbols:

d_1	distance between the auxiliary transducer and the reflector measured along the axis of symmetry
d_h	distance between the auxiliary transducer and the active element of the hydrophone measured along the axis of symmetry
d_m	distance between the auxiliary transducer and the last minimum of the acoustic pressure amplitude along the axis of symmetry of the auxiliary transducer
R_{RT}	amplitude reflection coefficient for the reflector/water interface
Z_{RT}	characteristic acoustic impedance of the reflector
J_p	reciprocity coefficient for plane waves
S_t^*	apparent transmitting current response of an auxiliary transducer
M_t^*	apparent receiving voltage response of an auxiliary transducer
p_a	acoustic pressure generated by a transducer at its surface
p_i	acoustic pressure incident on a transducer surface
p_h	acoustic pressure incident on the hydrophone surface
I_t	transmitting current driven to a transducer
U_t	voltage generated by a transducer in the receiving mode
G_{th}	correction that accounts for the diffraction in the propagation field and is related to the waveform generation by the transducer and the reception by the hydrophone
G_{tt}	correction that accounts for the diffraction in the propagation field and is related to the generation and the reception by the transducer
U_{load}	voltage measured with the transducer coupled to the system
I_{sc}	current measured over a short circuit jumper replacing the transducer

9 Free field reciprocity calibration

9.1 General

Replace the existing text by the following:

This clause specifies the primary reference measurement procedure (see JCGM 200:2012, 2.8 [79]) calibration of **hydrophones** under **free field** conditions using the principle of reciprocity.

Add the following new note:

NOTE The free field condition can be achieved in a confined water space by following any of a variety of measurement procedures, such as with the use of tone-burst (time-gated sine wave – see 10.5.3), time-delay spectrometry [63, 68], frequency modulated chirp [80, 81] or other techniques [82].

9.4 Two-transducer reciprocity calibration method

9.4.1 Apparatus

Replace the existing subclause title and text by the following:

9.4.1 Auxiliary transducers

Circularly plane piston auxiliary transducers should be used to generate the ultrasonic field in the frequency range of interest, limited to the maximum range between 1 MHz and 15 MHz. The effective radiation area (A_{ER}) shall be determined, according to IEC 61689, for each transducer and at all frequencies the transducer is intended to be used. If a frequency modulated chirp is to be used as excitation signal, the A_{ER} shall be determined at least in the minimum, maximum and one intermediate frequency in the range of interest.

The position of the last minimum of acoustic pressure amplitude along the axis of symmetry, d_m, shall be determined with an uncertainty not larger than 1 mm. It shall be done as an on-axis line scan, according to IEC 61689, at the same frequencies the A_{ER} was determined. The near field distance produced by the auxiliary transducer is defined as $N_1 = a_t^2/\lambda$, where λ is the ultrasonic wavelength in water at the frequency of operation and $a_t = \sqrt{2\lambda d_m + \lambda^2}$ is the effective radius of the ultrasonic transducer.

NOTE Focusing auxiliary transducers can be used, but several corrections need to be applied, and this document is only intended for plane-piston transducers. A detailed implementation of a reciprocity-based calibration method using focusing transducers can be found in [84].

The effective radiation area (A_{ER}) is used in the equations of Annex K to properly assess the diffraction correction and the reciprocity coefficient for plane waves, whilst the last minimum of pressure amplitude along the axis of symmetry (d_m) is used to indirectly define the near field distance (N_1), being $N_1 = (2\lambda d_m + \lambda^2)/\lambda$. Although both quantities A_{ER} and d_m are directly linked for ideal transducers, both shall be determined experimentally according to IEC 61689.

9.4.2 Procedure

Replace the existing subclause title and text by the following:

9.4.2 Reflector

The reflector should comprise a flat surface whose smallest linear dimension shall be at least four times the effective radius of the ultrasonic transducer a_t. The reflector shall also be flat to ±10 µm, with a surface finish good to ±5 µm (surface roughness: R_v < 5 µm; R_p < 5 µm; R_a < 1 µm). The thickness of the reflector shall be such that the first reflection from the rear surface will not interfere with that directly from the front surface for any of the excitation signals to be used. Special attention shall be given for long burst or low-rate frequency modulated chirps, mainly at the lowest frequencies of interest.

The amplitude reflection coefficient for the reflector/water interface R_{RT} shall be experimentally determined, for instance by the relation $R_{RT} = (Z_{RT} - \rho c)/(Z_{RT} + \rho c)$, were ρc is the characteristic acoustic impedance of the water and Z_{RT} is the characteristic acoustic impedance of the reflector.

NOTE R_v is the maximum valley depth, R_p is the maximum peak height and R_a is the arithmetic average describing the reflector profile roughness amplitude parameters.

Add the following new subclauses:

9.4.3 Measurement field

As both the auxiliary transducer and the **hydrophone** have finite apertures, a diffraction pattern is present in the ultrasonic field. To minimize uncertainties due to the analytical or numerical corrections to be applied to the measurement quantities, the nearest measurement shall be performed at least at 0,9 × N_1, and the furthest distance shall not be larger than 2,2 × N_1. Water-air surface and tank walls shall be far enough from the ultrasonic path such that any reflected waveform will not interfere with the direct waveform at the measurement spot.

If any structure is too close to the direct ultrasonic waveform path, it shall be covered with absorbing lining to minimize the interference with the measurement signal, and concern about that interference shall be included in the uncertainty budget.

9.4.4 Reciprocity approach

Reciprocity can be established as a primary **hydrophone** calibration method provided some practical and theoretical details are adopted. Annex K depicts the fundamentals of the reciprocity approach.

9.4.5 Measurement procedure

Several distinct setups (see Annex K [83, 84, 85]) could be used regarding the positioning of the three main elements of the two-transducer reciprocity calibration method: auxiliary transducer, reflector and **hydrophone**.

Regardless of the configuration adopted, the self-calibration of the auxiliary transducer is the first step, and it is done to quantify the acoustic pressure generated by the transducer in a defined spot in the ultrasonic field.

Annex K
(informative)

Two-transducer reciprocity calibration method

Replace the existing Annex K, added by Amendment 1, by the following:

K.1 General

The two-transducer reciprocity method involves the assessment of the acoustic pressure in a defined spot in the ultrasonic field. To accomplish that, the first step is to assess the ultrasonic field generated by an auxiliary transducer. The second step is to place the active element of the **hydrophone** to be calibrated in a defined spot for which the acoustic pressure can be defined as precisely as possible.

K.2 Fundamentals of reciprocity

A reversible transducer has an apparent transmitting current response $S_t^*(\omega)$ and apparent receiving voltage response $M_t^*(\omega)$ defined as

$$S_t^* = \frac{p_0(\omega)}{I_t(\omega)} \text{ and } M_t^* = \frac{U_t(\omega)}{p_i(\omega)} \tag{K.1}$$

where p_0 is the acoustic pressure generated by the auxiliary transducer at its surface, I_t is the transmitting current of the transducer, p_i is the acoustic pressure incident on the transducer surface and U_t is the voltage generated by the transducer in the receiving mode.

NOTE The term 'acoustic pressure' is used in Annex K, although it is recognized that in any practical situation this quantity will vary spatially. Similarly, the electrical output of transducer devices used in reception mode will be dependent on the acoustic pressure spatially-averaged on their active surface.

If the transducer is reciprocal, the reciprocity coefficient for plane waves J_p relates $S_t^*(\omega)$ and $M_t^*(\omega)$ as follows:

$$J_p = \frac{M_t^*(\omega)}{S_t^*(\omega)} \tag{K.2}$$

By definition, $J_p = \frac{2A_{ER}}{\rho c}$ $J_p = \frac{2A_{ER}}{\rho c}$.

If the wave generated by a reciprocal transducer propagates in water and reflects off with a normal incidence at a reflector distant d_1 from the transducer surface placed on its axis of symmetry, it produces an incident wave whose acoustic pressure can be measured by the reciprocal transducer. Relating the definition by Equation (K.3)

$$p_i(\omega) = p_0(\omega) R_{RT} e^{-2\alpha d_1} G_{tt} \tag{K.3}$$

where α is the amplitude attenuation coefficient of plane waves in water and G_{tt} is the correction due to the fact that the returning waveform is generated and measured by a finite transducer, i.e. it accounts for the diffraction in the propagation field and is related to the generation and reception by the transducer. Combining Equations (K.1), (K.2) and (K.3), the acoustic pressure generated by a reciprocal transducer at its surface is related to electrical and geometrical quantities as follows:

$$p_0(\omega) = \sqrt{U_t(\omega) I_t(\omega) \frac{\rho c}{2 A_{ER} R_{RT} e^{-2\alpha d_1} G_{tt}}} \, . \tag{K.4}$$

A normal incidence reflection on the reflector is necessary for the self-calibration. This is ensured by maximizing the waveform reflection from the reflector as measured by the transducer. The driven electrical current I_t is measured with the auxiliary transducer in the output mode. The input voltage U_t is measured when the auxiliary transducer is in the input mode. It should be an open-circuit voltage, and electrical corrections should be applied to the measured current and voltage.

In sequence, the **hydrophone** active element is placed in a determined spot in the ultrasonic field, and the acoustic pressure is maximized in order to assure the alignment of the **hydrophone** active element symmetry axis and the transducer symmetry axis. The acoustic pressure at this point is calculated using the following expression:

$$p_h(\omega) = p_0(\omega) e^{-\alpha d_h} G_{th} \tag{K.5}$$

where p_h is the measured acoustic pressure incident on the **hydrophone's** active element if the **hydrophone** were removed, d_h is the distance from the transducer surface to the active hydrophone element measured on the symmetry axis, and G_{th} is the correction that accounts for the diffraction in the propagation field and is related to the generation transducer and the reception by the **hydrophone**.

The open-circuit voltage from the **hydrophone** U_h should be measured with p_h incident on its active element. The end of cable sensitivity is therefore given as

$$M(\omega) = \frac{U_h(\omega)}{p_h(\omega)} \tag{K.6}$$

K.3 Electrical quantities

The transmitting current, I_t, shall be measured as precisely as possible, which can be performed in many different ways. Measuring the voltage drop across a calibrated impedance or using a current probe are typical electrical setups.

The output voltage from the transducer in the receiving mode, U_t, shall be measured unloaded by the transducer, i.e. as an open circuit voltage. One way to perform that is to measure the current over a short circuit replacing the transducer. The open circuit voltage is

$$U_t(\omega) = U_{load}(\omega) \frac{I_{sc}(\omega)}{I_t(\omega)} \tag{K.7}$$

where U_{load} is the voltage measured with the transducer coupled to the system and I_{sc} is the current measured over a short circuit jumper replacing the transducer.

In the case of a constant load assumed throughout the calibration process, corrections described in Annex C could be applied directly to the final assessed sensitivity.

K.4 Diffraction correction and loss due to nonlinear sound propagation

Due to the finite size of auxiliary transducers and **hydrophones**, a diffraction pattern develops in the ultrasonic field. In the two-transducer reciprocity method, two diffraction corrections are applied: G_{th}, correction that accounts for the diffraction in the propagation field and is related to the waveform generation by the transducer and the reception by the **hydrophone**, and G_{tt}, correction due the generation and the reception by the transducer. Many references can be used to theoretically describe the diffraction loss in ultrasonic fields [83, 86, 87], and a numerical implementation of diffraction corrections can be applied [88, 89, 90, 91].

K.5 Ultrasonic field

For the two-transducer reciprocity calibration, the ultrasonic field is shaped by the influence of many aspects, mainly:

- diffraction pattern for both the auxiliary transducer and hydrophone (see K.3);
- signal type (see Annex G and [8, 80]);
- reflector reflection coefficient (see 9.4.2);
- water path attenuation (see [92]);
- speed of sound (see [36]).

The amplitude attenuation coefficient for plane ultrasonic waves, α, in the megahertz frequency range is proportional to f^2, and should be taken from a polynomial fit as a function of temperature T in the temperature range from 0 °C to 60 °C [92]:

$$\alpha / f^2 = \begin{pmatrix} 5{,}685 \cdot 10^1 - 3{,}025 \cdot 10^0 \{T\} \\ + 1{,}174 \cdot 10^{-1} \{T\}^2 - 2{,}954 \cdot 10^{-3} \times \{T\}^3 \\ + 3{,}970 \cdot 10^{-5} \{T\}^4 - 2{,}111 \cdot 10^{-7} \{T\}^5 \end{pmatrix} \times 10^{-15} \mathrm{Hz}^{-2} \cdot \mathrm{m}^{-1} \quad \text{(K.8)}$$

NOTE 1 $\{T\}$ denotes the numerical value of the temperature in °C.

NOTE 2 If the amplitude attenuation coefficient in m^{-1} is going to be given in dB m^{-1}, its numerical value should be multiplied by $20 \cdot \log_{10}(e) = 8{,}69$.

The speed of sound is presented in tables in [36], and polynomial fits are available for different accuracies, temperature ranges, and barometric pressures. The contribution for the uncertainty budget should be taken into account regarding the formula used to assess the speed of sound.

a) Temperature range: 0 °C to 100 °C at atmospheric pressure; accuracy better than 0,02 ms^{-1} (see [93])

$$c = \begin{pmatrix} 1402{,}39 + 5{,}03836 \{T\} - 0{,}0581173 \{T\}^2 \\ + 3{,}34638 \cdot 10^{-4} \{T\}^3 - 1{,}48260 \cdot 10^{-6} \{T\}^4 \\ + 3{,}16585 \cdot 10^{-9} \{T\}^5 \end{pmatrix} \mathrm{m} \cdot \mathrm{s}^{-1} \quad \text{(K.9)}$$

b) Temperature range: 10 °C to 40 °C at atmospheric pressure; accuracy better than 0,18 ms^{-1} (see [93])

$$c = \left(1405{,}03 + 4{,}624 \{T\} - 0{,}0383 \{T\}^2\right) \mathrm{m} \cdot \mathrm{s}^{-1} \quad \text{(K.10)}$$

c) Temperature range: 15 °C to 35 °C at atmospheric pressure; accuracy better than 0,20 ms^{-1} (see [94])

$$c = \left(1404{,}3 + 4{,}7\ \{T\} - 0{,}04\ \{T\}^2\right)\mathrm{m \cdot s^{-1}} \quad \text{(K.11)}$$

For the atmospheric pressure dependence of the speed of sound, see [95].

K.6 Experimental setup

K.6.1 General

Different experimental arrangements have been proposed to perform the two-transducer reciprocity calibration. Regardless of the electrical setup, the main concern in the experimental preparation comprises the positioning of the auxiliary transducer, reflector, and **hydrophone**. Three experimental setups are shown, each of them presenting advantages and drawbacks.

K.6.2 Twisting reflector

Figure K.1 depicts an arrangement in which the reflector is twisted between the two steps of the calibration procedure. Care should be taken to avoid a large angle of rotation of the reflector. A maximum of 10° would be acceptable, but the uncertainty of the **hydrophone** voltage measurement due to non-normal reflection should be considered. Moreover, for large membrane **hydrophones**, it could be a negative issue to set the rotation angle small. Another negative aspect of this arrangement is that it may not be simple to rotate large and heavy stainless steel reflectors with appropriate accuracy.

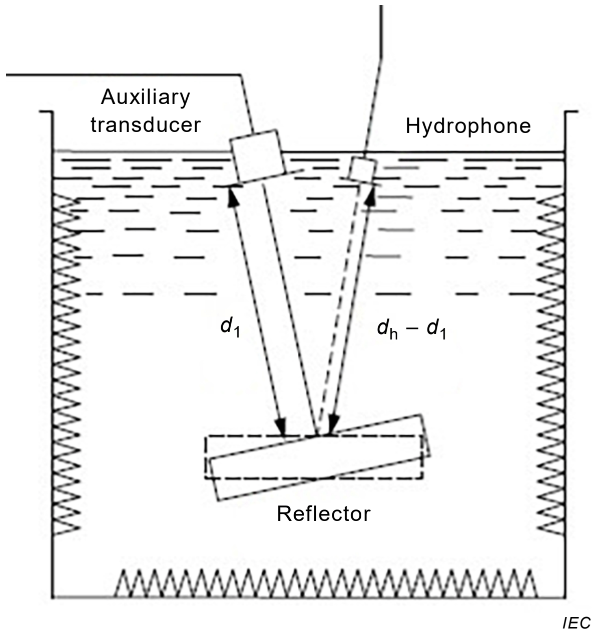

Figure K.1 – Experimental setup with a twisting reflector [83]

K.6.3 Translational reflector

Figure K.2 discloses an arrangement in which the reflector is inserted in the path between the auxiliary transducer and the **hydrophone**.

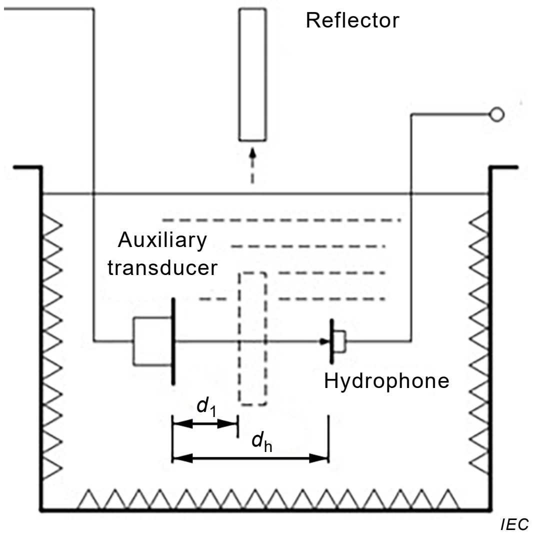

Figure K.2 – Experimental setup with a translational reflector [84]

K.6.4 Translational auxiliary transducer

In Figure K.3, the **hydrophone** and the reflector remain still during the measurement procedure, and the moving element is the transducer.

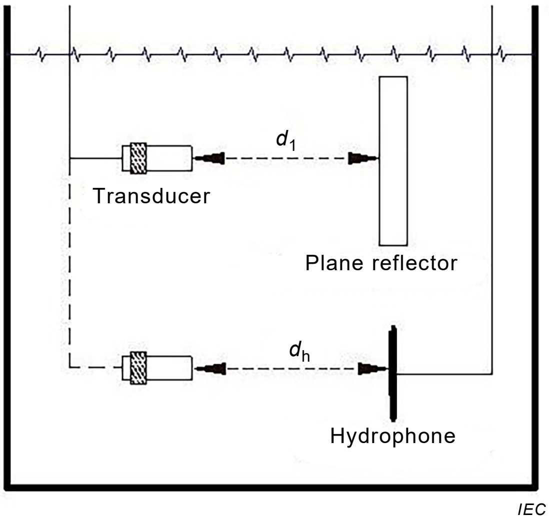

Figure K.3 – Experimental setup with a translational auxiliary transducer [85]

Bibliography

Add the following references:

[79] BIPM JCGM 200:2012, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*.

[80] ISAEV, A.E. and Matveev A.N. Calibration of Hydrophones in a Field with Continuous Radiation in a Reverberating Pool. *Acoustical Physics*, 2009, vol. 55, no. 6, p. 762-770.

[81] COSTA-FELIX, R.P.B. and MACHADO, J.C. Output bandwidth enhancement of a pulsed ultrasound system using a flat envelope and compensated frequency-modulated input signal: Theory and experimental applications. *Measurement*, 2015, vol. 69, p. 146-154.

[82] ISAEV, A.E. A Quality Criterion for Obtaining Free-Field Conditions when Calibrating a Hydroacoustic Receiver in a Water Tank with Reflecting Sides. *Measurement Techniques*, 2014, vol. 57, no. 5, p. 549-556.

[83] BRENDEL, K., LUDWIG, G. Calibration of Ultrasonic Standard Probe Transducers. *Acustica*, 1976, vol. 36, p. 203.

[84] SHOU W, DUAN S, HE P, XIA R, QIAN D. Calibration of a Focusing Transducer and Miniature Hydrophone As Well As Acoustic Power Measurement Based on Free-Field Reciprocity in a Spherically Focused Wave Field. *IEEE Trans. Ultrason. Ferroelectr. Freq. Contr.*, 2006, vol. 53 no. 3, p. 564-570.

[85] OLIVEIRA, E.G., COSTA-FELIX, R.P.B. and MACHADO, J.C. Primary reciprocity-based method for calibration of hydrophone magnitude and phase sensitivity: complete tests at frequencies from 1 to 7 MHz. *Ultrasonics*, 2015, vol. 58, p. 87-95.

[86] BRENDEL, K., LUDWIG, G. Measurement of Ultrasonic Diffraction Loss for Circular Transducers. *Acustica*, 1975, vol. 32, p.110.

[87] BEISSNER, K. Free-field Reciprocity Calibration in the Transition Range between Near Field and Far Field. *Acustica*, 1980, vol. 46, p.162.

[88] FAY, B. Numerische Berechnung der Beugungsverluste im Schallfeld von Ultraschallwandlern. *Acustica*, 1976, vol. 36, p. 209.

[89] KHIMUNIN, A.S. Numerical Calculation of the Diffraction Corrections for the Precise Measurement of Ultrasound Absorption. *Acustica*, 1972, vol. 27, p. 173.

[90] BEISSNER, K. Exact integral expression for the diffraction loss of a circular piston source. *Acustica*, 1981, vol. 49, p. 212.

[91] YOSHIOKA, SATO, KIKUCHI and MATSUDA. Influence of ultrasonic nonlinear propagation on hydrophone calibration using two-transducer reciprocity method. *Jpn. J. App. Phys.*, 2006, vol. 45, No.5B, p.4547-4549.

[92] PINKERTON, J.M.M. A Pulse Method for the Measurement of Ultrasonic Absorption in Liquids Results for Water. *Nature*, 1947, vol. 160, p. 128.

[93] BILANIUK, N, WONG, G.S.K. Erratum: Speed of sound in pure water as a function of temperature, *J. Acoust. Soc. Am.*, 1996, vol. 99, no. 5, p. 3257.

[94] LUBBERS, J, GRAAFF, R. A simple and accurate formula for the sound velocity in water, *Ultrasound Med. Biol*., 1998, vol 24, no. 7, p. 1065-1068.

[95] BELOGOL'SKII, V.A., SEKOYAN, S.S., SAMORUKOVA, L.M. STEFANOV, S.R., Levtsov, V.I. Pressure dependence of the sound velocity in distilled water, *Measurement Techniques*, 1999, vol. 42, no. 4, p. 406-413.

CONTENTS

INTRODUCTION

The spatial and temporal distribution of acoustic pressure in an ultrasonic field in a liquid medium is commonly determined using miniature ultrasonic **hydrophones**. These devices are not absolute measurement instruments and require calibration. The purpose of this part of IEC 62127 is to specify those calibration methods to be used in determining the response of a **hydrophone** in the ultrasonic range, i.e. above 20 kHz up to a frequency of 40 MHz. The main **hydrophone** application in this context lies in the measurement of ultrasonic fields emitted by medical diagnostic equipment in water. **Hydrophone** behaviour over this wide frequency band is required in order to reliably characterize the acoustic parameters of the applied acoustic field. In particular, the frequency range above 15 MHz is important to fully characterize this equipment, primarily due to the increased appearance of high-frequency components in the ultrasonic signals, caused by nonlinear propagation. In addition, the number of medical ultrasonic systems that use frequencies above 15 MHz, particularly intra-operative probes, is growing. It has turned out in recent years that the **hydrophone** response below 0,5 MHz is also required to reliably determine the peak-negative (rarefactional) acoustic pressure.

While the term "**hydrophone**" can be used in a wider sense, it is understood here as referring to miniature piezoelectric **hydrophones**. It is this instrument type that is used today in various areas of medical ultrasonics and, in particular, to characterize quantitatively the field structure of medical diagnostic instruments. With regard to other pressure sensor types, such as those based on fibre optics, some of the requirements of this standard are applicable to these as well but others are not. If in the future these other "**hydrophone**" types gain more importance in field measurement practice, their characteristics and calibration will have to be dealt with in a revised version of this standard or in a separate one.

NOTE This standard covers the ultrasonic frequency range, from 20 kHz to an upper frequency of 40 MHz. Standards dealing with **hydrophone** properties (IEC 62127-3) and **hydrophone** use (IEC 62127-1) are being developed in parallel as part of a programme of maintenance activities aimed at restructuring and merging, where possible, all existing ultrasonic **hydrophone** standards. This will eventually lead to unified standards covering the whole field of practical **hydrophone** application.

ULTRASONICS — HYDROPHONES —

Part 2: Calibration for ultrasonic fields up to 40 MHz

1 Scope

This part of IEC 62127 specifies:

- absolute **hydrophone** calibration methods;
- relative (comparative) **hydrophone** calibration methods.

Recommendations and references to accepted literature are made for the various relative and absolute calibration methods in the frequency range covered by this standard.

This standard is applicable to

- **hydrophones** used for measurements made in water and in the ultrasonic frequency range up to 40 MHz;

  NOTE 1 Although some physiotherapy medical applications of medical ultrasound are developing which operate in the frequency range 40 kHz to 100 kHz, the primary frequency range of diagnostic imaging remains above 2 MHz. It has recently been established that, even in the latter case, the **hydrophone** response at substantially lower frequencies can influence measurements made of key acoustic parameters [1].

- **hydrophones** employing circular piezoelectric sensor elements, designed to measure the pulsed wave and continuous wave ultrasonic fields generated by ultrasonic equipment;

  NOTE 2 Some hydrophones can have non-circular active elements, arising from slight deviations from a circular structure caused, for example by electrode structure, or conversely, the active elements can actually be squares. The clauses within this standard remain valid, although, in these cases, special attention should be paid to the directional response and to the effective radii of the active element through various axes of rotation.

- **hydrophones** with or without a hydrophone pre-amplifier.

2 Normative references

The following referenced documents are indispensable for the application 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.

[A1] IEC 60050-801, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics* [A1]

IEC 60565, *Underwater acoustics – Hydrophones – Calibration in the frequency range 0,01 Hz to 1 MHz*

[A1] IEC 61161, *Ultrasonics – Power measurement – Radiation force balances and performance requirements*

IEC 61828, *Ultrasonics – Focusing transducers – Definitions and measurement methods for the transmitted fields*

IEC 62127-1:2007, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*
Amendment 1:2013 [A1]

IEC 62127-3, *Ultrasonics – Hydrophones – Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz*