IEC 62127-3

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Ultrasonics – Hydrophones –
Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz

Ultrasons – Hydrophones –
Partie 3: Propriétés des hydrophones pour les champs ultrasoniques jusqu'à 40 MHz

IEC 62127-3:2007

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ULTRASONICS – HYDROPHONES –

Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz

FOREWORD

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International Standard IEC 62127-3 has been prepared by IEC technical committee 87: Ultrasonics

IEC 62127-1, IEC 62127-2 and IEC 62127-3 are being published simultaneously. Together these cancel and replace IEC 60866:1987, IEC 61101:1991, IEC 61102:1991, IEC 61220:1993 and IEC 62092:2001.

This bilingual version (2012-06) corresponds to the monolingual English version, published in 2007-08.

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

Enquiry draft	Report on voting
87/354/CDV	87/373/RVC

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

The French version of this standard has not been voted upon.

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

A list of all parts of IEC 62127 series, published under the general title *Ultrasonics – Hydrophones,* can be found on the IEC website.

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn,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.

INTRODUCTION

The spatial and temporal distribution of acoustic pressure in an ultrasonic field in a liquid medium is commonly determined using miniature ultrasonic **hydrophones**. The properties of these **hydrophones** have been dealt with in a number of IEC standards in various aspects. The purpose of this part of IEC 62127 is to bring together all these specifications and to establish a common standard on the properties of ultrasonic **hydrophones**. The main **hydrophone** application in this context is the measurement of ultrasonic fields emitted by medical diagnostic equipment in water. Other medical applications are field measurements for therapy equipment such as that used in lithotripsy, high-intensity focused ultrasound (HIFU) and physiotherapy. **Hydrophones** are also used extensively in non-medical applications for both product development and quality control including:

– mapping of the ultrasound field within ultrasonic cleaning baths;
– characterization of acoustic fields used in transmission measurement systems (e.g. ultrasonic spectrometers, ultrasonic attenuation meters and velocimeters);
– characterization of acoustic fields used in reflection measurement systems (e.g. Doppler flowmeters).

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 ultrasonics and, in particular, to quantitatively characterize 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 properties will have to be dealt with in a revised version of this standard or in a separate one.

Underwater **hydrophones** as covered by IEC 60500 and IEC 60565 are not included in this standard, although there is an overlap in the frequency ranges. Underwater **hydrophones** are used in natural waters, even in the ocean, and this leads to different technical concepts and requirements. In addition, the main direction of acoustic incidence in underwater applications is typically at right angles to the **hydrophone axis**, whereas it is assumed in this standard that it is in the direction of the **hydrophone axis**.

In the past, ultrasonic **hydrophones** have been applied almost exclusively as amplitude sensors. At present a change can be seen and it is increasingly considered useful to have additional phase information, which, however, is only possible if the phase characteristics of the **hydrophone** have been determined during calibration. In this standard, therefore, requirements are specified for the amplitude aspect of the **hydrophone** sensitivity, and recommendations are provided for the phase aspect, as an option to be considered.

ULTRASONICS – HYDROPHONES –

Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz

1 Scope

This part of IEC 62127 specifies relevant **hydrophone** characteristics.

This standard is applicable to:

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

– **hydrophones** used for measurements made in water;

– **hydrophones** with or without an associated 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.

IEC 62127-1, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*

IEC 62127-2, *Ultrasonics – Hydrophones – Part 2: Calibration for ultrasonic fields up to 40 MHz*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in IEC 62127-1, IEC 62127-2 and the following apply.

3.1
directional response

description, generally presented graphically, of the response of a **hydrophone**, as a function of direction of propagation of the incident plane sound wave, in a specified plane through the **reference centre** and at a specified frequency

NOTE Definition adopted from IEC 60565:2006.

3.2
effective hydrophone radius

a_h, a_{h3}, a_{h6}

radius of a stiff disc receiver **hydrophone** that has a predicted **directional response** function with an angular width equal to the observed angular width

NOTE 1 The angular width is determined at a specified level below the peak of the **directional response** function. For the specified levels of 3 dB and 6 dB, the radii are denoted by a_{h3} and a_{h6} respectively.

NOTE 2 The radius is usually the function of frequency. For representative experimental data, see [1].

NOTE 3 The **effective hydrophone radius** is expressed in metres (m).

3.3
electric load impedance
$\underline{Z}_L$
complex electric input impedance (consisting of a real and an imaginary part) to which the **hydrophone** or **hydrophone assembly** output is connected or is to be connected

NOTE The **electric load impedance** is expressed in ohms (Ω).

3.4
end-of-cable
specification that relates to the end of the integral output cable if the **hydrophone** or **hydrophone assembly** is provided with such a cable; if the **hydrophone** or **hydrophone assembly** is not provided with an integral output cable, the specification relates to the output connector firmly connected with the **hydrophone** or **hydrophone assembly**, not to an extra cable

3.5
end-of-cable loaded sensitivity
end-of-cable loaded sensitivity of a **hydrophone** or **hydrophone assembly**
M_L
ratio of the instantaneous voltage at the end of any integral cable or output connector of a **hydrophone** or **hydrophone assembly**, when connected to a specified **electric load impedance**, to the instantaneous acoustic pressure in the undisturbed **free field** of a plane wave in the position of the **reference centre** of the **hydrophone** if the **hydrophone** were removed

NOTE **End-of-cable loaded sensitivity** is expressed in volts per pascal (V/Pa).

3.6
end-of-cable open-circuit sensitivity

end-of-cable open-circuit sensitivity of a hydrophone

M_c
ratio of the instantaneous, open-circuit voltage at the end of any integral cable or output connector of a **hydrophone** to the instantaneous acoustic pressure in the undisturbed **free field** of a plane wave in the position of the **reference centre** of the **hydrophone** if the **hydrophone** were removed

NOTE 1 **End-of-cable open-circuit sensitivity** is expressed in volts per pascal (V/Pa).

NOTE 2 This corresponds to the **free field** sensitivity as defined in IEC 60565:2006, 3.15.

3.7
free field
sound field in a homogeneous and isotropic medium in which the effects of boundaries are negligible

NOTE Definition adopted from IEC 60565:2006, 3.13.

3.8
hydrophone geometrical radius
geometrical radius of a hydrophone active element
a_g
radius defined by the dimensions of the active element of a **hydrophone**

NOTE The **hydrophone geometrical radius** is expressed in metres (m).

3.9
hydrophone
transducer that produces electric signals in response to waterborne acoustic signals

[IEV 801-32-26]

3.10
hydrophone assembly
combination of **hydrophone** and **hydrophone pre-amplifier**

3.11
hydrophone axis
nominal symmetry axis of the **hydrophone** active element

NOTE Unless stated otherwise (explicitly and quantitatively) by the manufacturer, it is understood for the purposes of this standard that this is given by the apparent geometrical symmetry axis of the **hydrophone**.

3.12
hydrophone pre-amplifier
active electronic device connected to, or to be connected to, a particular **hydrophone** and reducing its output impedance

NOTE 1 A **hydrophone pre-amplifier** requires a supply voltage (or supply voltages).

NOTE 2 The **hydrophone pre-amplifier** may have a forward voltage transmission factor of less than one, i.e. it need not necessarily be a voltage amplifier in the strict sense.

3.13
reference centre
point on or near a **hydrophone** about which its acoustic receiving sensitivity is defined

NOTE 1 Unless stated otherwise (explicitly and quantitatively) by the manufacturer, it is understood for the purposes of this standard that this is given by the geometrical centre of the front surface of the **hydrophone** active element.

NOTE 2 Definition adopted from IEC 60565, 3.25.

3.14
uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

NOTE 1 See the ISO *Guide to the Expression of Uncertainty in Measurement* [2], 2.2.3

NOTE 2 Definition adopted from IEC 62127-1.

4 List of symbols

a_g **hydrophone** geometrical radius

a_h **effective hydrophone radius** (a_{h3}, a_{h6}: with special reference to a 3 dB or 6 dB definition, respectively)

c speed of sound in a medium

f frequency

$\underline{M}$ general symbol for the complex **hydrophone** sensitivity, $M=|\underline{M}|$ being its modulus and arg($\underline{M}$) being its argument (= phase angle)

M_c end-of-cable open-circuit sensitivity

M_L end-of-cable loaded sensitivity

$\underline{Z}_h$ complex electric output impedance of a **hydrophone** or **hydrophone assembly**

$\underline{Z}_L$ electric load impedance

θ angle of incidence of an ultrasonic wave with respect to the **hydrophone axis** (θ_3, θ_6: with special reference to 3 dB and 6 dB defined levels)

5 Hydrophone characteristics

5.1 General

For a full characterization of the **hydrophone** performance in the frequency range of this standard, the following information is required. Examples of information on **hydrophone** characteristics are provided in Annex A.

5.2 Basic information

The following shall be briefly stated:

– the basic physical principles of the transduction process, the type of sensor material involved, the form and geometrical dimensions (diameter, thickness) of the **hydrophone** active element and the needle diameter in case of a needle **hydrophone**;

– the configuration and design of the **hydrophone**;

– whether or not a pre-amplifier is associated with the **hydrophone**; if the pre-amplifier can be disconnected from the **hydrophone**, clear information shall be given as to which pre-amplifier type belongs to which **hydrophone** type;

– the nominal direction of ultrasonic incidence in relation to the **hydrophone**.

NOTE The last point is important, as it has been found in the literature [3] that even with membrane **hydrophones**, the response might change upon reversal of the ultrasonic propagation direction in relation to the **hydrophone**.

The following should be briefly stated:

– the frequency of the fundamental thickness resonance of the **hydrophone** active element;

– the size and weight of the **hydrophone**;

– in the case of a membrane **hydrophone**, the acoustic reflection and transmission factor (preferably as a function of frequency).

General note relating to 5.3 and 5.4: if phase information is available, the phase angle (which equals the argument of the complex **hydrophone** sensitivity) should be stated in addition to the sensitivity (which equals the modulus of the complex **hydrophone** sensitivity), as well as the frequency dependence of the phase angle in addition to the frequency dependence of the sensitivity.

5.3 Sensitivity

The end-of-cable sensitivity of the **hydrophone** or **hydrophone assembly** shall be stated in V/Pa or in decimal submultiples, or as a logarithmic level in dB with reference to a stated sensitivity value.

If a pre-amplifier contributes to the sensitivity value given, this shall be stated.

It shall be stated whether the sensitivity value given is understood as the **end-of-cable open-circuit sensitivity** or as the **end-of-cable loaded sensitivity**. In the latter case, the relevant electric loading conditions shall be stated, i.e. the **electric load impedance**, in order to obtain the stated sensitivity.

The **uncertainty** of the stated sensitivity shall be given.

The frequency interval over which the sensitivity is given and over which the **uncertainty** applies shall be stated. For the purposes of this standard, sensitivity and **uncertainty** values may be given separately for several frequency intervals.

The methods by which the sensitivity and its **uncertainty** have been obtained shall be described.

The temperature dependence of the sensitivity shall be given. The **hydrophone** sensitivity shall be stated as a function of the water temperature, at least over the temperature range 19 °C to 25 °C, or the particular water temperature to which the stated sensitivity relates, shall be stated together with the temperature coefficient of the sensitivity.

A recommended calibration period shall be provided in the instructions for use. This recommendation shall be followed, unless otherwise stated by specific device application standards.

NOTE 1 A calibration period of one year will be appropriate in most cases.

The **reference centre** shall be stated if the sensitivity does not relate to the geometrical centre of the front surface of the **hydrophone** active element.

NOTE 2 This is particularly important for any phase considerations.

The direction of acoustic incidence shall be stated if the sensitivity does not relate to an incidence in the direction of the **hydrophone axis**.

5.4 Frequency response

5.4.1 Stated frequency band

The frequency band claimed for the **hydrophone** or **hydrophone assembly** shall be stated by giving the lower frequency limit and the upper frequency limit. The end-of-cable sensitivity of the **hydrophone** or **hydrophone assembly** shall be constant over the stated frequency band with a tolerance which shall also be stated.

5.4.2 Frequency dependence

The end-of-cable sensitivity or sensitivity level of the **hydrophone** or **hydrophone assembly** as a function of frequency shall be stated either graphically or as a list of values and over a frequency range containing at least the frequency band claimed under 5.4.1. If it is given as a list of values or as discrete points in a graph, the frequency distance between adjacent points should be low enough so that all important details of the frequency dependence are shown and the sensitivity level does not vary by more than ±1 dB between adjacent points.

The frequency response may be given in terms of absolute sensitivity values or in a relative representation, relative with reference to the absolute sensitivity of the **hydrophone** or **hydrophone assembly** at a certain frequency. In the case of the relative representation, the reference sensitivity and the frequency to which it applies shall be stated.

The statement of the frequency response shall refer to the same conditions (i.e. loaded or open-circuit output of the **hydrophone** or **hydrophone assembly**) as the sensitivity statement in accordance with 5.3.

If the **uncertainty** of the sensitivity values in the frequency response representation differs from the general **uncertainty** assessment of 5.3, this shall be clearly stated and the new or additional **uncertainty** shall be given. If the frequency response is presented graphically only, the additional **uncertainty** due to reading the graph shall be less than 10 % of the total **uncertainty** listed.

If the frequency response is given as a list of absolute sensitivity values (end-of-cable, loaded or open-circuit), the sensitivity statement in accordance with 5.3 may be omitted.

NOTE 1 The frequency response might depend on the electric load conditions.

NOTE 2 If, in a practical application, the **hydrophone** or **hydrophone assembly** is used with subsequent electronic components such as an amplifier, oscilloscope, etc., the frequency response of the whole system will also be, of course, influenced by the frequency response of these additional components.

5.5 Directional response

5.5.1 General

The **directional response** of the **hydrophone** shall be stated at both the lower and upper limits of the frequency band claimed under 5.4.1. The determination method used shall also be stated. The **directional response** shall also be stated at the geometric mean of the lower and upper frequency limits, and close to the fundamental thickness resonance if this resonance is inside the claimed frequency band.

The **directional response** should be measured by rotating the **hydrophone** about an axis, which passes through the **reference centre** and which is perpendicular to the **hydrophone axis**, at least from –35° up to +35° (with the **hydrophone axis** as reference), or at least from the first left-hand minimum to the first right-hand minimum, whichever of the angular spans is the greater. If this method is used, this shall be done twice, namely about two rotational axes perpendicular to each other. If, in the plane perpendicular to its axis, a **hydrophone** has a certain distinct direction (for example that of the electric leads in the case of a membrane **hydrophone**), the rotational axes should be in this direction and perpendicular to it. If the active element is non-circular, one of the rotational axes shall be in the direction of the largest dimension. The directions of the rotational axes shall be identified on the **hydrophone** using a mark or in the accompanying literature.

The measurement of the directional response shall be carried out in an almost plane wave ultrasonic field.

If the active element is irregular in shape, or has more than two symmetry axes, the **directional response** should be measured around additional axes.

Each of the resulting **directional responses** obtained from the measurements shall be stated.

5.5.2 Symmetry of directional response

If, in any of the **directional response** results obtained, the angle between the direction of maximum response and the **hydrophone axis** is greater than 1/10 of the angular difference between the left-hand –6 dB direction and the right-hand –6 dB direction, this shall be stated and the deviation-of-axis angle shall be given. The sensitivity level in the direction of the **hydrophone axis** shall be not lower than the maximum in any other direction minus 2 dB.

The symmetry of any directional response should be such that if a normalized sensitivity level of –6 dB occurs for some particular direction subtending a certain angle to the direction of maximum sensitivity (0 dB), then the sensitivity level measured on the opposite side subtending the same angle to the direction of maximum sensitivity shall be within the range –6 dB ± 3 dB.

NOTE Problems in field measurement practice will arise if the direction of maximum **hydrophone** response varies significantly with frequency.

5.6 Effective radius

From the **directional response** results obtained in accordance with 5.5, a value for the **effective radius** of the **hydrophone** active element shall be derived and stated as follows, and again at the frequencies given in 5.4.1

If, in the **directional response** considered, the angular difference between the left-hand –3 dB direction and the right-hand –3 dB direction is $2\theta_3$ and the angular difference between the left-hand –6 dB direction and the right-hand –6 dB direction is $2\theta_6$, the following formulas for the **effective radii** shall apply under the assumption of circular geometry: