IEC TS 62903

Edition 1.0 2018-01

TECHNICAL SPECIFICATION

Ultrasonics – Measurements of electroacoustical parameters and acoustic output power of spherically curved transducers using the self-reciprocity method

IEC TS 62903:2018-01(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 17.140.50 ISBN 978-2-8322-5026-6

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IEC TS 62903, which is a Technical Specification, has been prepared by IEC technical committee 87: Ultrasonics.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
87/652/DTS	87/659/RVDTS

Full information on the voting for the approval of this technical specification 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.

In this standard, the following print types are used:

- **terms defined in Clause 3: in bold type**.

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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

An ultrasonic transducer is an important acoustic device that can act as a transmitter or a receiver in the applications of medical ultrasound, non-destructive testing, and ultrasonic materials processing. The performance of a transducer is a decisive factor that governs the device's range of applicability, efficiency and quality control in the manufacturing. The mechanisms, transmitting fields, performances, and measurement methods used for these transducers have been studied over the past few decades. However, the electroacoustical characterization and measurement methods applied for spherically curved transducers have not been defined in standard documents for either terms or protocols.

This document defines the relevant electroacoustical parameters for these devices and establishes the self-reciprocity measurement method for spherically curved concave focusing transducers.

ULTRASONICS – MEASUREMENTS OF ELECTROACOUSTICAL PARAMETERS AND ACOUSTIC OUTPUT POWER OF SPHERICALLY CURVED TRANSDUCERS USING THE SELF-RECIPROCITY METHOD

1 Scope

This document, which is a Technical Specification,

a) establishes the free-field convergent spherical wave self-reciprocity method for ultrasonic transducer calibration,

b) establishes the measurement conditions and experimental procedure required to determine the transducer's electroacoustic parameters and acoustic output power using the self-reciprocity method,

c) establishes the criteria for checking the reciprocity of these transducers and the linear range of the focused field, and

d) provides guiding information for the assessment of the overall measurement uncertainties for radiation conductance.

This document is applicable to:

i) circular spherically curved concave focusing transducers without a centric hole working in the linear amplitude range,

ii) measurements in the frequency range 0,5 MHz to 15 MHz, and

iii) acoustic pressure amplitudes in the focused field within the linear amplitude range.

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 60050-801:1994, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-801:1994 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
p_{av}
average acoustic pressure
acoustic pressure averaged over the **effective area** of the transducer

Note 1 to entry: **Average acoustic pressure** is expressed in pascals (Pa).

3.2
$\boldsymbol{r_{av}(\beta)}$
average amplitude reflection coefficient
ratio of the **free-field** echo **average acoustic pressure** $p_{av}(\beta)$ reflected by the reflector on the geometric focal plane over the space area coincident with the **effective area** of the spherically curved transducer of focus half-angle β, if the transducer were removed, to the **reference acoustic pressure** p_0 on the **effective area** of the transducer in a non-attenuation medium with negligible diffraction, $r_{av}(\beta) = p_{av}(\beta)/p_0$

3.3
G_{sf}
diffraction correction coefficient
ratio of the **average acoustic pressure** over the spherical segment surface of the spherically curved transducer's virtual image at a position in the distance of twice **geometric focal length** from the transducer, if an ideal reflecting mirror were located on the geometric focal plane, to the **reference acoustic pressure** of the transducer in the **free-field** of a non-attenuation medium

3.4
A
effective area
<transducer> area of the radiating surface of a theoretically predicted transducer with specific field distribution characteristics that are approximately the same as those of a real transducer of the same type

Note 1 to entry: For a spherically curved transducer, the theoretically predicted acoustic pressure distribution on the geometric focal plane of a transducer should be approximately the same as that of the real transducer with the same **geometric focal length** when operating at the same frequency.

Note 2 to entry: The half-aperture of an **effective area** is also named the effective half-aperture or the effective radius.

Note 3 to entry: The **effective area** of a transducer is expressed in metres squared (m^2).

3.5
$\eta_{a/e}$
electroacoustic efficiency
ratio of the acoustic output power to the electric input power

3.6
electroacoustical reciprocity principle
electroacoustical reciprocity theorem
principle that the ratio of the **free-field voltage (current) sensitivity** of a **reciprocal transducer** as a receiver, to the **transmitting response to current (voltage)** of the **reciprocal transducer** as a projector is constant

Note 1 to entry: This principle is independent of the construction of the **reciprocal transducer**.

3.7
free-field
sound field in a homogeneous isotropic medium whose boundaries exert a negligible effect on the sound wave

[SOURCE: IEC 61161:2013, 3.2]

3.8
M
free-field voltage sensitivity of a spherically curved transducer
receiving voltage response of a spherically curved transducer
ratio of the open-circuit output voltage of a spherically curved transducer within the field of a point source at the **geometric focus** to the **free-field** acoustic pressure acting on the space surface where the transducer surface was present, if that transducer were removed

Note 1 to entry: **Free-field voltage sensitivity of a spherically curved transducer** is expressed in volts per pascal (V/Pa).

3.9
geometric beam boundary
surface containing straight lines passing through the **geometric focus** and all points around the periphery of the transducer aperture

Note 1 to entry: The definition applies to transducers of known construction.

[SOURCE: IEC 61828:2006, 4.2.36]

3.10
F_{geo}
geometric focal length
distance from the **geometric focus** to the ultrasonic transducer's focusing surface

Note 1 to entry: The definition applies to transducers with known construction and is equal to the radius of curvature of the radiating surface.

Note 2 to entry: The focusing surface is the surface of constant phase, whose periphery is coincident with the transducer's aperture.

Note 3 to entry: **Geometric focal length** is expressed in metres (m).

3.11
geometric focus
point for which all of the effective path lengths in a specified longitudinal plane are equal

Note 1 to entry: The **geometric focus** is also the point for which all waves from the transducer have the same delay as viewed in the approximation of geometrical acoustics neglecting diffraction.

[SOURCE: IEC 61828:2006, 4.2.39, modified – In the definition, the added explanation for the definition "Also, the point for which all...diffraction." has been moved to a Note to entry.]

3.12
$L_{M\text{pe}}$
pulse-echo sensitivity level
ratio of the received open-circuit voltage for the first echo signal of the spherically curved transducer when acting as a receiver to the exciting voltage of the transducer when it is transmitting a tone burst ultrasonic beam in a direction perpendicular to an ideal plane reflector (r = 1) at the geometric focal plane

Note 1 to entry: The ratio is expressed in decibels (dB).

3.13
G
radiation conductance
ratio of the acoustic output power and the squared effective transducer input voltage

Note 1 to entry: It is used to characterize the electrical to acoustical transfer of ultrasonic transducers.

Note 2 to entry: The frequency of the input voltage (or current) should be noted.

Note 3 to entry: **Radiation conductance** is expressed in siemens (S).

[SOURCE: IEC 61161:2013, 3.8, modified – In the definition, "RMS" has been replaced with "effective".]

3.14
reciprocal transducer
linear, passive and **reversible transducer**

Note 1 to entry: An example of a non-**reciprocal transducer** is one that mixes a magnetic field device with an electric field device.

[SOURCE: IEC 60565:2006, 3.24]

3.15
J
reciprocity parameter
<transducer> ratio of the **free-field** voltage sensitivity of a transducer as a receiver to the **transmitting response to the current** of the transducer as a projector, or the ratio of the **free-field current sensitivity** of a transducer as a receiver to the **transmitting response to the voltage** of the transducer as a projector

Note 1 to entry: The **reciprocity parameter** of a spherically curved transducer, $J = J_{sf}$, is equal to the quotient of twice the **effective area** of the transducer divided by the acoustic characteristic impedance of the medium, i.e.

$$J_{sf} = 2A/(\rho\ c)$$

where

A is the **effective area** of curved surface of the spherically curved transducer;

ρ is the (mass) density of the medium;

c is the speed of sound in the medium (usually water).

Note 2 to entry: The **reciprocity parameter** is expressed in watts per pascal squared (W/Pa^2).

3.16
p_0
reference acoustic pressure
product of the uniform normal particle velocity on the spherically curved surface of the transducer and the characteristic impedance of the medium

Note 1 to entry: **Reference acoustic pressure** is expressed in pascals (Pa).

3.17
reversible transducer
transducer capable of acting as a projector as well as a receiver

[SOURCE: IEC 60565:2006, 3.26, modified – In the definition, "hydrophone" has been replaced with "receiver".]

3.18
self-reciprocity method
transducer calibration method based on the reciprocity principle that uses the received echo signal from the plane reflector that is set perpendicular to the incident beam axis of the transducer

3.19
S_I
transmitting response to current
transmitting current response
ratio of the **reference acoustic pressure** on the radiating surface of a transducer in the **free-field** in the absence of interference effects to the current flowing through the electrical terminals of a projector at a given frequency

Note 1 to entry: **Transmitting response to current** is expressed in pascals per ampere (Pa/A).

3.20
S_U
transmitting response to voltage
transmitting voltage response
the ratio of the **reference acoustic pressure** on the radiating surface of a transducer in the **free-field** in the absence of interference effects to the exciting voltage of a projector at a given frequency

Note 1 to entry: **Transmitting response to voltage** is expressed in pascals per volt (Pa/V).

4 Symbols

a	effective half-aperture, effective radius of transducer
A	**effective area** of transducer
c	speed of sound in sound propagating medium usually in water
d	distance from the centre of the transmitting surface of the transducer to the reflecting plane of the reflector in the geometric focal plane
f_0	resonant frequency
f_c	central frequency
F_{geo}	(= R) **geometric focal length**
G	**radiation conductance**
G_{sf}	**diffraction correction coefficient** for spherically curved transducer in free-field self-reciprocity calibration
h	height (depth) at the centre of a spherical segment
I	acoustic intensity
I_T, I_{Trms}	exciting current amplitude, effective exciting current
I_k	short-circuit current amplitude of the generator
I_{echo}	first echo current amplitude
J	**reciprocity parameter** of transducer
J_{sf}	**reciprocity parameter** of spherically curved transducer
k	(= $2\pi/\lambda$), circular wave number
k_m	ratio of the acoustic pressure at the **geometric focus** to the **reference acoustic pressure** on the radiation surface of the transducer
l	distance from the centre of receiving surface of the hydrophone to the centre of the transmitting surface of the transducer along their common axis after alignment
L_{Mpe}	**pulse-echo sensitivity level**
M	**free-field voltage sensitivity (receiving voltage response) of a spherically curved transducer**
p_0	**reference acoustic pressure** of a radiating surface
P	acoustic output power
P_e	electrical input power
q	(=(1 + cosβ)/2), ratio of the true time-average intensity I to the time-average derived intensity I_p at the **geometric focus**
Q_m	mechanical quality factor
r	amplitude reflection coefficient
$r_{av}(\beta)$	**average amplitude reflection coefficient** on a plane reflector in the geometric focal plane in water for a spherically curved transducer
R	radius of curvature

S_I	**transmitting response to current**
$S_{I\mathrm{f}}$	transmitting response at **geometric focus** to current
S_U	**transmitting response to voltage**
$S_{U\mathrm{f}}$	transmitting response at **geometric focus** to voltage
Δt_{F}	acoustic pulse transit time
U_0	open-circuit voltage amplitude of tone burst generator
U_{T}, U_{Trms}	exciting voltage amplitude, exciting effective voltage of the transducer
U_1	maximum of the first echo voltage amplitude received by the transducer to be calibrated in self-reciprocity calibration process
$U_{I\mathrm{T}}$	output voltage of the current probe picked up the exiting current of the transducer
$U_{I\mathrm{echo}}$	output voltage of the current probe picked up the first echo current of the transducer
$U_{I\mathrm{k}}$	output voltage of the current probe picked up the short-circuit current of the tone burst generator
U_{rms}	effective voltage
v	particle velocity
w_3	–3 dB beamwidth on geometric focal plane
w_6	–6 dB beamwidth on geometric focal plane
Y_{T}	electric admittance of transducer
Z_{i}	electric output impedance of generator
Z_{T}	electric impedance of transducer
α	acoustic attenuation coefficient in medium (usually in water)
β	(= arcsin(a/R)), focus half-angle
θ_{e}	electric impedance angle
ρ	(mass) density of the sound propagating medium (usually water)
$\eta_{\mathrm{a/e}}$	**electroacoustic efficiency**
λ	wavelength
τ	pulse duration

5 General

The transducer characteristics include the ultrasonic field parameters and the transmission and reception performance parameters.

The focused field performance parameters include the effective half-aperture (the effective radius), the beam width, the **effective area**, the **geometric focal length**, and the focus half-angle for spherically curved transducers.

The transmission performance parameters include the **radiation conductance**, the acoustic output power, the **free-field transmitting response to current (voltage)**, the **electroacoustic efficiency**, and the electric impedance.

The reception performance parameter is the **free-field voltage sensitivity**.

The transmission-reception parameter is the **pulse-echo sensitivity level.**

In this document, the beam profile method using a hydrophone is defined for the measurement of the field performance parameters; the **self-reciprocity method** is defined for