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Ultrasonics – Field characterization – In situ exposure estimation in finite-amplitude ultrasonic beams

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ULTRASONICS – FIELD CHARACTERIZATION – IN SITU EXPOSURE ESTIMATION IN FINITE-AMPLITUDE ULTRASONIC BEAMS

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 61949, 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
87/349/DTS	87/364A/RVC

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

This publication is being issued as a technical specification (according to 3.1.1.1 of the IEC/ISO directives, Part 1) as a “prospective standard for provisional application” in the field of finite-amplitude ultrasonic beams, because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an “International Standard”. It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Acoustic waves of finite amplitude generate acoustic components at higher frequencies than the fundamental frequency. This provides a mechanism for acoustic attenuation which is not significant at lower acoustic pressure, and for which there is substantial experimental and theoretical evidence (Tables A.1 and A.2). The generation of harmonic frequency components, and their associated higher attenuation coefficient, can occur very strongly when high amplitude pulses, associated with the use of ultrasound in medical diagnostic applications, propagate through water. This fact is of importance when measurements of **acoustic pressure**, made in water, are used to estimate **acoustic pressure** in another medium, or when intensity derived from hydrophone measurements in water is used to estimate intensity within another medium. In particular, errors occur in the estimation of the **acoustic pressure** and intensity *in situ*, if it is assumed that the propagation of ultrasound through water, and through tissue, is linear.

Standards for measurement of frequency-rich pulse waveforms in water are well established (IEC 62127-1). Whilst means to quantify nonlinear behaviour of medical ultrasonic beams are specified, no procedures are given for their use. Since that time IEC 60601-2-37 and IEC 62359 have introduced "attenuated" acoustic quantities, which are derived from measurements in water and intended to enable the estimation of *in situ* exposure for safety purposes.

This Technical Specification describes means to allow "attenuated" acoustic quantities to be calculated under conditions where the associated acoustic measurements, made in water using standard procedures, may be accompanied by significant finite-amplitude effects. A number of alternative methods have been proposed (Table B.1).The approach used in this Technical Specification is aligned with the proposal of the World Federation for Ultrasound in Medicine and Biology [1][1)], that "Estimates of tissue field parameters at the point of interest should be based on derated values calculated according to an appropriate specified model and be extrapolated linearly from small signal characterization of source-field relationships."

1) Figures in square brackets refer to the Bibliography.

ULTRASONICS – FIELD CHARACTERIZATION – IN SITU EXPOSURE ESTIMATION IN FINITE-AMPLITUDE ULTRASONIC BEAMS

1 Scope

This Technical Specification establishes:

- the general concept of the limits of applicability of acoustic measurements in water resulting from finite-amplitude acoustic effects;
- a method to ensure that measurements are made under quasi-linear conditions in order to minimise finite-amplitude effects, which may be applied under the following conditions:
  - to acoustic fields in the frequency range 0,5 MHz to 15 MHz;
  - to acoustic fields generated by plane sources and focusing sources of amplitude gain up to 12;
  - at all depths for which the maximum acoustic pressure in the plane perpendicular to the acoustic axis lies on the axis;
  - to both circular and rectangular source geometries;
  - to both continuous-wave and pulsed fields;
- the definition of an acoustic quantity appropriate for establishing quasi-linear conditions;
- a threshold value for the acoustic quantity as an upper limit for quasi-linear conditions;
- a method for the estimation of attenuated acoustic quantities under conditions of nonlinear propagation in water.

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 61161, *Ultrasonics – Power – Radiation force balances and performance requirements*

IEC 62127-1:2007 *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*

3 Terms and definitions

For the purposes of this document, the following definitions apply.

3.1
acoustic attenuation coefficient
coefficient intended to account for ultrasonic attenuation of tissue between the source and a specified point

Symbol: α

Unit: decibels per centimetre per megahertz, dB cm^{-1} MHz^{-1}

[IEC 62359, definition 3.1]

3.2
acoustic pressure
pressure minus the ambient pressure at a particular instant in time and at a particular point in the acoustic field

Symbol: p

Unit: pascal, Pa

[IEC 62127-1, definition 3.33, modified]

3.3
acoustic working frequency
arithmetic mean of the frequencies, f_1 and f_2, at which the acoustic pressure spectrum is 3 dB below the peak value

Symbol: f_{awf}

Unit: Hertz, Hz

[IEC 62127-1, definition 3.3.2, modified]

3.4
attenuated acoustic pulse waveform
the temporal waveform of the instantaneous acoustic pressure calculated in a specified attenuation model and at a specified point. See 3.1 of IEC 62127-1 for acoustic pulse waveform

Symbol: $p_\alpha(t)$

Unit: pascal, Pa

3.5
attenuated acoustic power
value of the acoustic output power calculated for a specified attenuation model and at a specified point

Symbol: P_α

Unit: watt, W

[IEC 62359, definition 3.3]

3.6
attenuated peak-rarefactional acoustic pressure
the **peak-rarefactional acoustic pressure** calculated in a specified attenuation model and at a specified point

Symbol: $p_{r,\alpha}$

Unit: pascal, Pa

[IEC 62359, definition 3.4, modified]

3.7
attenuated pulse-intensity integral
the pulse-intensity integral calculated for a specified attenuation model and at a specified point

Symbol: $I_{pi,\alpha}$

Unit: joule per metre squared, J m^{-2}

[IEC 62359, definition 3.6, modified]

3.8
attenuated spatial-peak temporal-average intensity
the spatial-peak temporal-average intensity calculated in a specified attenuation model

Symbol: $I_{\text{spta},\,\alpha}$

Unit: watt per metre squared, W m^{-2}

[IEC 62359, definition 3.7, modified]

3.9
attenuated temporal-average intensity
the temporal-average intensity calculated in a specified attenuation model and at a specified point

Symbol: $I_{\text{ta},\,\alpha}$

Unit: watt per metre squared, W m^{-2}

[IEC 62359, definition 3.8, modified]

3.10
beam area
area in a specified plane perpendicular to the beam axis consisting of all points at which the pulse-pressure-squared integral is greater than a specified fraction of the maximum value of the pulse-pressure-squared integral in that plane

Symbol: A_b

Unit: metre squared, m^2

[IEC 62127-1, definition 3.7, modified]

3.11
local area factor

the square root of the ratio of the **source aperture** to the **beam area** at the point of interest. The relevant **beam area**, A_b, is that for which the maximum pulse-pressure-squared integral is greater than 0,135 (that is, 1/e^2) times the maximum value in the cross-section. If the **beam area** at the -6 dB level, $A_{b,-6dB}$, is known, the **beam area** can be calculated as $A_b = A_{b,-6dB}/0{,}69$: (0,69 = 3ln(10)/10).

$$F_a = \sqrt{\frac{0{,}69 A_{\text{SAeff}}}{A_{b,-6\text{dB}}}} .$$

Symbol: F_a

3.12
local distortion parameter
an index which permits the prediction of nonlinear propagation effects along the axis of a focused beam. The local distortion parameter is calculated according to 6.1.1

Symbol: σ_q

3.13
mean peak acoustic pressure
the arithmetic mean of the **peak-rarefactional acoustic pressure** and the **peak-compressional acoustic pressure**

Symbol: p_m

Unit: pascal, Pa

3.14
nonlinear threshold value
a value of any nonlinear propagation index Y, such that for $Y \leq \tau$ the beam has quasi-linear characteristics at the selected point and for $Y > \tau$ the beam has nonlinear characteristics at the selected point

Symbol: τ

3.15
peak-rarefactional acoustic pressure
maximum of the modulus of the negative instantaneous **acoustic pressure** in an acoustic field or in a specified plane during an acoustic repetition period. Peak-rarefactional acoustic pressure is expressed as a positive number

Symbol: p_r

Unit: pascal, Pa.

[IEC 62127-1, definition 3.44, modified]

3.16
peak-compressional acoustic pressure
maximum positive instantaneous **acoustic pressure** in an acoustic field or in a specified plane during an acoustic repetition period

Symbol: p_c

Unit: pascal, Pa.

[IEC 62127-1, definition 3.45, modified]

3.17
quasi-linear
a condition of the ultrasonic field between the source and a plane at a specified axial depth for which, at every point, less than a specified, small proportion of the energy has transferred from the fundamental frequency to other frequencies through nonlinear propagation effects.

3.18
scaling factor
the ratio between the **mean peak acoustic pressure** at a location close to the transducer to the **mean peak acoustic pressure** at the same location under **quasi-linear** conditions, where quasi-linearity is determined at the point of interest.

Symbol: S

3.19
source aperture
equivalent aperture for an ultrasonic transducer, measured within the –20 dB pulse-pressure-squared-integral contour, in the **source aperture plane**

Symbol: A_{SAeff}

Unit: metre squared, m^2

[IEC 61828, definition 4.2.65, modified]

3.20
source aperture plane
closest possible measurement plane to the external transducer aperture that is perpendicular to the beam axis

[IEC 61828, definition 4.2.67]

3.21
transducer aperture width
full width of the transducer aperture along a specified axis orthogonal to the beam axis

Symbol: L_{TA}

Unit: metre, m

[IEC 61828, definition 4.2.74, modified]

4 List of symbols

α	acoustic attenuation coefficient
A_b	beam area
A_{SAeff}	source aperture
β	nonlinearity parameter for water, ≅ 3,5
c	speed of sound
f_{awf}	acoustic working frequency
F_a	local area factor
$I_{pi,\alpha}$	attenuated pulse-intensity integral
$I_{pi,q}$	reduced pulse-intensity integral
$I_{spta,\alpha}$	attenuated spatial-peak temporal-average intensity
$I_{spta,q}$	reduced spatial-peak temporal-average intensity
$I_{ta,\alpha}$	attenuated temporal-average intensity
$I_{ta,q}$	reduced temporal-average intensity
L	discontinuity length
L_{TA}	transducer aperture width
P	total acoustic output power
P_α	attenuated acoustic power
p	acoustic pressure
$p_\alpha(t)$	attenuated acoustic pulse waveform
$p_q(t)$	acoustic pulse waveform under quasi-linear conditions
p_c	peak-compressional acoustic pressure
$p_{c,s}$	peak-compressional acoustic pressure close to the source for scaling
$p_{c,s,m}$	pre-correction peak-compressional acoustic pressure close to the source for scaling
$p_{c,s,q}$	reduced peak-compressional acoustic pressure close to the source for scaling
p_m	mean peak acoustic pressure
p_r	peak-rarefactional acoustic pressure
$p_{r,\alpha}$	attenuated peak-rarefactional acoustic pressure
$p_{r,q}$	reduced peak-rarefactional acoustic pressure