

BS EN 61689:2013



BSI Standards Publication

Ultrasonics — Physiotherapy systems — Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz

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National foreword

This British Standard is the UK implementation of EN 61689:2013. It is identical to IEC 61689:2013. It supersedes BS EN 61689:2007, which will be withdrawn on 02 April 2016.

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.

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English version

**Ultrasonics -
Physiotherapy systems -
Field specifications and methods of measurement in the frequency range
0,5 MHz to 5 MHz
(IEC 61689:2013)**

Ultrasons -
Systèmes de physiothérapie -
Spécifications des champs et méthodes
de mesure dans la gamme de fréquences
de 0,5 MHz à 5 MHz
(CEI 61689:2013)

Ultraschall -
Physiotherapiesysteme -
Feldspezifikation und Messverfahren im
Frequenzbereich von 0,5 MHz bis 5 MHz
(IEC 61689:2013)

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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 87/522/FDIS, future edition 3 of IEC 61689, prepared by IEC TC 87 "Ultrasonics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61689:2013.

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) 2014-01-02
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2016-04-02

This document supersedes EN 61689:2007.

EN 61689:2013 includes the following significant technical changes with respect to EN 61689:2007:

- restriction introduced of 0,2 W/cm² effective intensity during hydrophone measurements for treatment heads with $ka \leq 20$, to limit the likelihood of cavitation;
- a change in the factor F_{ac} , to determine the **effective radiating area**, from 1,354 to 1,333;
- change to SI units for terms and definitions;
- closer alignment and re-ordered, updated definitions in line with standards in EN 62127 series;
- minor arithmetical errors corrected in data analysis;
- inconsistencies and errors in symbol usage removed throughout;
- large number of editorial and formal corrections made;
- changes introduced to references in the bibliography.

This standard should be read in conjunction with EN 60601-2-5, which, as indicated in its preface, will itself be revised in order to be compatible with this standard.

NOTE The following print types are used:

- Requirements: in Arial 10 point
- Notes: in Arial 8 point
- Words in **bold** in the text are defined in Clause 3
- Symbols and formulae: *Times New Roman + Italic*
- Compliance clauses : *in Arial Italic*

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Endorsement notice

The text of the International Standard IEC 61689:2013 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61828	NOTE Harmonized as EN 61828.
IEC 62127-2	NOTE Harmonized as EN 62127-2.
IEC 62127-3	NOTE Harmonized as EN 62127-3.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60601-1	-	Medical electrical equipment - Part 1: General requirements for basic safety and essential performance	EN 60601-1	-
IEC 60601-2-5	-	Medical electrical equipment - Part 2-5: Particular requirements for the basic safety and essential performance of ultrasonic physiotherapy equipment	EN 60601-2-5	-
IEC 61161	2013	Ultrasonics - Power measurement - Radiation force balances and performance requirements	EN 61161	2013
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

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INTRODUCTION

Ultrasound at low megahertz frequencies is widely used in medicine for the purposes of physiotherapy. Such equipment consists of a generator of high frequency electrical energy and usually a hand-held **treatment head**, often referred to as an applicator. The **treatment head** contains a transducer, usually a disk of piezoelectric material, for converting the electrical energy to **ultrasound** and is often designed for contact with the human body.

ULTRASONICS – PHYSIOTHERAPY SYSTEMS – FIELD SPECIFICATIONS AND METHODS OF MEASUREMENT IN THE FREQUENCY RANGE 0,5 MHz TO 5 MHz

1 Scope

This International Standard is applicable to **ultrasonic equipment** designed for physiotherapy containing an **ultrasonic transducer** generating continuous or quasi-continuous wave ultrasound in the frequency range 0,5 MHz to 5 MHz.

This standard only relates to **ultrasonic physiotherapy equipment** employing a single plane non-focusing circular transducer per **treatment head**, producing static beams perpendicular to the face of the **treatment head**.

This standard specifies:

- methods of measurement and characterization of the output of **ultrasonic physiotherapy equipment** based on reference testing methods;
- characteristics to be specified by manufacturers of **ultrasonic physiotherapy equipment** based on reference testing methods;
- guidelines for safety of the ultrasonic field generated by **ultrasonic physiotherapy equipment**;
- methods of measurement and characterization of the output of **ultrasonic physiotherapy equipment** based on routine testing methods;
- acceptance criteria for aspects of the output of **ultrasonic physiotherapy equipment** based on routine testing methods.

Therapeutic value and methods of use of **ultrasonic physiotherapy equipment** are not covered by the scope of this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60601-1, *Medical electrical equipment – Part 1: General requirements for basic safety and essential performance*

IEC 60601-2-5, *Medical electrical equipment – Part 2-5: Particular requirements for the basic safety and essential performance of ultrasonic physiotherapy equipment*

IEC 61161: 2013, *Ultrasonics – Power measurement – 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*
Amendment 1: 2013

3 Terms and definitions

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

NOTE SI units (see ISO/IEC Directives – Part 2:2011, Annex I b) are used in the Notes to entry below certain parameter definitions for defining certain parameters, such as beam areas and intensities. It may be convenient to use decimal multiples or submultiples in practice but care should be taken in using decimal prefixes in combination with units when using and calculating numerical data. For example, beam area may be specified in cm^2 and intensities in W/cm^2 or mW/cm^2 .

3.1

absolute maximum rated output power

sum of the **rated output power**, the 95 % confidence overall uncertainty in the **rated output power**, and the maximum increase in the **rated output power** for a ± 10 % variation in the rated value of the mains voltage

Note 1 to entry: The possibility of variation in the **rated output power** resulting from ± 10 % variation in the rated value of the mains voltage should be checked by using a variable output transformer between the mains voltage supply and the **ultrasonic physiotherapy equipment**. See Clause A.2 for further guidance.

Note 2 to entry: **Absolute maximum rated output power** is expressed in watt (W).

3.2

active area coefficient

Q

quotient of the **active area gradient**, m , and the **beam cross-sectional area** at 0,3 cm from the face of the **treatment head**, $A_{\text{BCS}}(0,3)$

Note 1 to entry: **Active area coefficient** is expressed in per metre (m^{-1}).

3.3

active area gradient

m

gradient of the line connecting the **beam cross-sectional area** at 0,3 cm from the face of the **treatment head**, $A_{\text{BCS}}(0,3)$, and the **beam cross-sectional area** at the position of the last axial maximum acoustic pressure, $A_{\text{BCS}}(z_N)$, versus distance

Note 1 to entry: **Active area gradient** is expressed in metre (m).

3.4

absolute maximum beam non-uniformity ratio

beam non-uniformity ratio plus the 95 % confidence overall uncertainty in the **beam non-uniformity ratio**

3.5

absolute maximum effective intensity

value of the **effective intensity** corresponding to the **absolute maximum rated output power** and the **absolute minimum effective radiating area** from the **equipment**

3.6

absolute minimum effective radiating area

effective radiating area minus the 95 % confidence overall uncertainty in the **effective radiating area**

3.7

acoustic frequency

acoustic-working frequency

f_{awf}

frequency of an acoustic signal based on the observation of the output of a **hydrophone** placed in an acoustic field at the position corresponding to the **spatial-peak temporal-peak acoustic pressure**

Note 1 to entry: The signal is analysed using either the **zero-crossing acoustic-working frequency** technique or a spectrum analysis method. Acoustic-working frequencies are defined in 3.7.1 and 3.7.2.

Note 2 to entry: In a number of cases the present definition is not very helpful or convenient, especially for **broadband transducers**. In that case a full description of the frequency spectrum should be given in order to enable any frequency-dependent correction to the signal.

Note 3 to entry: **Acoustic frequency** is expressed in hertz (Hz).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.3]

3.7.1 arithmetic-mean acoustic-working frequency

f_{awf}
arithmetic mean of the most widely separated frequencies f_1 and f_2 , within the range of three times f_1 , at which the magnitude of the acoustic pressure spectrum is 3 dB below the peak magnitude

Note 1 to entry: This frequency is intended for pulse-wave systems only.

Note 2 to entry: It is assumed that $f_1 < f_2$.

Note 3 to entry: If f_2 is not found within the range $< 3f_1$, f_2 is to be understood as the lowest frequency above this range at which the spectrum magnitude is 3 dB below the peak magnitude.

[SOURCE: IEC 62127-1:2007 Amendment 1:2013 definition 3.3.2, modified – Note 3 to entry has been added]

3.7.2 zero-crossing acoustic-working frequency

f_{awf}
number, n , of consecutive half-cycles (irrespective of polarity) divided by twice the time between the commencement of the first half-cycle and the end of the n -th half-cycle

Note 1 to entry: None of the n consecutive half-cycles should show evidence of phase change.

Note 2 to entry: The measurement should be performed at terminals in the receiver, that are as close as possible to the receiving transducer (**hydrophone**) and, in all cases, before rectification.

Note 3 to entry: This frequency is determined according to the procedure specified in IEC/TR 60854.

Note 4 to entry: This frequency is intended for **continuous-wave** systems only.

[SOURCE: IEC 62127-1:2007 Amendment 1:2013 to, definition 3.3.1,]

3.8 acoustic pulse waveform

temporal waveform of the **instantaneous acoustic pressure** at a specified position in an acoustic field and displayed over a period sufficiently long to include all significant acoustic information in a single pulse or tone-burst, or one or more cycles in a **continuous wave**

Note 1 to entry: Temporal waveform is a representation (e.g. oscilloscope presentation or equation) of the **instantaneous acoustic pressure**.

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.1, modified – deletion of NOTE 2]

3.9 acoustic repetition period

arp
pulse repetition period equal to the time interval between corresponding points of consecutive cycles for **continuous wave** systems

Note 1 to entry: **Acoustic repetition period** is expressed in second (s).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.2, modified – the definition cited above is more specific for non-scanning systems]

3.10

amplitude modulated wave

wave in which the ratio $p_p / \sqrt{2}p_{\text{rms}}$ at any point in the **far field** on the **beam alignment axis** is greater than 1,05, where p_p is the **temporal-peak acoustic pressure** and p_{rms} is the **rms acoustic pressure**

3.11

attachment head

accessory intended to be attached to the **treatment head** for the purpose of modifying the ultrasonic beam characteristics

[SOURCE: IEC 60601-2-5:2009, definition 201-3-202]

3.12

beam alignment axis

straight line joining two points of **spatial-peak temporal-peak acoustic pressure** on two plane surfaces parallel to the faces of the **treatment head**. One plane is at a distance of approximately $A_{\text{ERN}}/(\pi\lambda)$ where A_{ERN} is the nominal value of the **effective radiating area** of the **treatment head** and λ is the wavelength of the **ultrasound** corresponding to the nominal value of the **acoustic-working frequency**. The second plane surface is at a distance of either $2A_{\text{ERN}}/(\pi\lambda)$ or $A_{\text{ERN}}/(3\pi\lambda)$, whichever is the more appropriate. For the purposes of alignment, this line may be projected to the face of the **treatment head**

Note 1 to entry: If the nominal value of the **effective radiating area** is unknown, then another suitable area may be used to define the **beam alignment axis** such as the area of the active element of the **ultrasonic transducer**.

Note 2 to entry: As the **beam alignment axis** is used purely for the purposes of alignment, the definitions of specific distances may be relaxed slightly to reflect the constraints of the measurement system employed. For example, some **treatment heads** will have $A_{\text{ERN}}/(\pi\lambda)$ considerably greater than 12 cm, in which case a maximum distance of 12 cm may be used to define the first plane. General guidelines for determining the **beam alignment axis** are given in 7.3.

3.13

beam cross-sectional area

A_{BCS}

minimum area in a specified plane perpendicular to the **beam alignment axis** for which the sum of the **mean square acoustic pressure** is 75 % of the **total mean square acoustic pressure**

Note 1 to entry: **Beam cross-sectional area** is expressed in square metre (m²).

Note 2 to entry: The rationale supporting the definition is described in Annex D.

3.14

beam maximum intensity

product of the **beam non-uniformity ratio** and **effective intensity**

Note 1 to entry: **Beam maximum intensity** is expressed in watt per square metre (W/m²).

3.15

beam non-uniformity ratio

R_{BN}

ratio of the square of the **maximum rms acoustic pressure** to the spatial average of the square of the **rms acoustic pressure**, where the spatial average is taken over the **effective radiating area**. **Beam non-uniformity ratio** is given by:

$$R_{\text{BN}} = \frac{p_{\text{max}}^2 A_{\text{ER}}}{p_{\text{ms}\dagger} A_0} \quad (1)$$

where

p_{\max} is the **maximum r.m.s. acoustic pressure**;

A_{ER} is the **effective radiating area**;

p_{ms_t} is the **total mean square acoustic pressure**;

A_0 is the unit area for the raster scan.

3.16

beam type

descriptive classification for the ultrasonic beam in one of three types: **collimated, convergent or divergent**

3.17

continuous wave

wave in which the ratio $p_p/\sqrt{2}p_{\text{rms}}$, at any point in the **far field** on the **beam alignment axis**, is less than or equal to 1,05, where p_p is the **temporal-peak acoustic pressure** and p_{rms} is the **rms acoustic pressure**

3.18

collimated

beam for which the **active area coefficient**, Q , obeys the following inequality:

$$-0,05 \text{ cm}^{-1} \leq Q \leq 0,1 \text{ cm}^{-1}$$

3.19

convergent

beam for which the **active area coefficient**, Q , obeys the following inequality:

$$Q < -0,05 \text{ cm}^{-1}$$

3.20

divergent

beam for which the **active area coefficient**, Q , obeys the following inequality:

$$Q > 0,1 \text{ cm}^{-1}$$

3.21

duty factor

ratio of the **pulse duration** to the **pulse repetition period**

3.22

effective intensity

I_e

intensity given by $I_e = P/A_{\text{ER}}$ where P is the **output power** and A_{ER} is the **effective radiating area**

Note 1 to entry: **Effective intensity** is expressed in watt per square metre (W/m^2).

3.23

effective radiating area

A_{ER}

beam cross-sectional area determined at a distance of 0,3 cm from the front of the **treatment head**, $A_{\text{BCS}}(0,3)$, multiplied by a dimensionless factor, F_{ac} , given by:

$$F_{ac} = 1,333 \quad (2)$$

Note 1 to entry: The conversion factor F_{ac} is used here in order to derive the area close to the **treatment head** which contains 100 % of the **total mean square acoustic pressure**. The origin of the value of F_{ac} is described in Annex E, in references [1]¹ and [2] in Annex K.

Note 2 to entry: **Effective radiating area** is expressed in square metre (m²).

3.24

end-of-cable loaded sensitivity

end-of-cable loaded sensitivity of a hydrophone

end-of-cable loaded sensitivity of a hydrophone-assembly

$M_L(f)$

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 1 to entry: **End-of-cable loaded sensitivity** is expressed in volt per pascal (V/Pa).

[SOURCE: IEC 62127-3:2007, definition 3.5]

3.25

far field

region of the field where $z > z_T$ aligned along the beam axis for planar non-focusing transducers

Note 1 to entry: In the **far field**, the sound pressure appears to be spherically divergent from a point on or near the radiating surface. Hence the pressure produced by the sound source is approximately inversely proportional to the distance from the source.

Note 2 to entry: The term "**far field**" is used in this standard only in connection with non-focusing source transducers. For focusing transducers a different terminology for the various parts of the transmitted field applies (see IEC 61828).

Note 3 to entry: For the purposes of this standard, the **far field** starts at a distance where $z_T = A_{ERN}/(\pi\lambda)$ where A_{ERN} is the nominal value of the **effective radiating area** of the **treatment head** and λ is the wavelength of the **ultrasound** corresponding to the **acoustic working frequency**. This differs from the NOTE in IEC 62127-1 Amendment 1:2013.

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.28, modified – The above definition has replaced the Note 3 to entry]

3.26

hydrophone

transducer that produces electrical signals in response to waterborne acoustic signals

[SOURCE: IEC 60050-801:1994, definition 801-32-26]

3.27

instantaneous acoustic pressure

$p(t)$

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

Note 1 to entry: **Instantaneous acoustic pressure** is expressed in pascal (Pa).

[SOURCE: IEC 60050-802:2011, definition 802-01-03, modified – only grammatical, plus addition of the Note 1 to entry]

¹ Numbers in square brackets refer to the Bibliography.

3.28 maximum rms acoustic pressure

P_{\max}
maximum value of the **rms acoustic pressure** detected by a **hydrophone** over the entire acoustic field

Note 1 to entry: **Maximum rms acoustic pressure** is expressed in pascal (Pa).

3.29 mean square acoustic pressure

mean square of the **instantaneous acoustic pressure** at a particular point in the acoustic field. The mean is taken over an integral number of **acoustic repetition periods**

Note 1 to entry: In practice, the mean value is often derived from rms measurements.

Note 2 to entry: **Mean square acoustic pressure** is expressed in pascal squared (Pa²).

3.30 modulation waveform

temporal envelope waveform of the **amplitude modulated wave** at the point of **peak rms acoustic pressure** on the **beam alignment axis** and displayed over a period sufficiently long to include all significant acoustic information in the **amplitude modulated wave**

3.31 output power

P
time-average ultrasonic power emitted by a **treatment head of ultrasonic physiotherapy equipment** into an approximately free field under specified conditions in a specified medium, preferably in water

Note 1 to entry: **Output power** is expressed in watt (W).

[IEC 61161: 2013, definition 3.3, modified – **treatment head of ultrasonic physiotherapy equipment** instead of **ultrasonic transducer**]

3.32 peak rms acoustic pressure

maximum value of the **rms acoustic pressure** over a specified region, line or plane in an acoustic field

Note 1 to entry: **Peak rms acoustic pressure** is expressed in pascal (Pa).

3.33 pulse duration

time interval beginning at the first time the pressure amplitude exceeds a reference value and ending at the last time the pressure amplitude returns to that value. The reference value is equal to the sum of the minimum value of the pressure amplitude and 10 % of the difference between the maximum and minimum value of the pressure amplitude

Note 1 to entry: This definition differs from that in IEC 62127-1 Amendment 1:2013, from which it is derived, to account for incomplete modulation.

Note 2 to entry: **Pulse duration** is expressed in second (s).

3.34 pulse repetition period

prp
time interval between equivalent points on successive pulses or tone-bursts

Note 1 to entry: **Pulse repetition period** is expressed in second (s).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.51, modified – NOTE 1 from IEC 62127-1 Amendment 1:2013 not copied]

3.35 pulse repetition rate

prf

reciprocal of the pulse repetition period

Note 1 to entry: The **pulse repetition rate** is equal to the repetition frequency of the modulated waveform.

Note 2 to entry: The **pulse repetition rate** is expressed in hertz (Hz).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.52, modified – Note 1 to entry differs to the original NOTE 1]

3.36 rated output power

maximum **output power** of the **ultrasonic physiotherapy equipment** at the rated value of the mains voltage, with control settings configured to deliver maximum **output power**

Note 1 to entry: **Rated output power** is expressed in watt (W)

3.37 rms acoustic pressure

P_{rms}

root-mean-square (rms) of the **instantaneous acoustic pressure** at a particular point in an acoustic field

Note 1 to entry: The mean should be taken over an integral number of **acoustic repetition periods** unless otherwise specified.

Note 2 to entry: **rms acoustic pressure** is expressed in pascal (Pa).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.53]

3.38 spatial-peak temporal-peak acoustic pressure

P_{sptp}

larger of the **peak-compressional acoustic pressure** or the **peak-rarefactional acoustic pressure**

Note 1 to entry: **Spatial-peak temporal-peak acoustic pressure** is expressed in pascal (Pa).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.63]

3.39 temporal-maximum output power

P_{tm}

in the case of an **amplitude modulated wave**, the **temporal-maximum output power** is given by:

$$P_{tm} = \frac{1}{2} \left(\frac{P_p}{P_{rms}} \right)^2 P \quad (3)$$

where

P is the actual **output power** under **amplitude modulated wave** conditions;

P_p is the **temporal-peak acoustic pressure**;

P_{rms} is the true **rms acoustic pressure**.

Both p_p and p_{rms} are measured under **amplitude modulated wave** conditions and at a specified point on the **beam alignment axis**.

Note 1 to entry: **Temporal-maximum output power** is expressed in watt (W).

3.40 total mean square acoustic pressure

p_{ms_t}

sum of the **mean square acoustic pressure** values, each with a specified incremental area, in a specified plane over specified limits of summation

Note 1 to entry: **Total mean square acoustic pressure** is expressed in pascal squared (Pa²).

3.41 temporal-maximum intensity

I_m

in the case of an **amplitude modulated wave**, the **temporal-maximum intensity** is given by:

$$I_m = \frac{P_{tm}}{A_{ER}} \quad (4)$$

where

P_{tm} is the **temporal-maximum output power**;

A_{ER} is the **effective radiating area**.

Note 1 to entry: **Temporal-maximum intensity** is expressed in watt per square metre (W/m²).

3.42 temporal-peak acoustic pressure

p_{tp}

maximum value of the modulus of the **instantaneous acoustic pressure** at a particular point in an acoustic field

Note 1 to entry: **Temporal-peak acoustic pressure** is expressed in pascal (Pa).

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.67]

3.43 treatment head

assembly comprising one **ultrasonic transducer** and associated parts for local application of **ultrasound** to the patient

[SOURCE: IEC 60601-2-5:2009, definition 201.3.214, modified – The NOTE has not been included]

3.44 ultrasonic transducer

device capable of converting electrical energy to mechanical energy within the ultrasonic frequency range and/or reciprocally of converting mechanical energy to electrical energy

[SOURCE: IEC 62127-1:2007 Amendment 1:2013, definition 3.73]

3.45 ultrasound

acoustic oscillation whose frequency is above the high-frequency limit of audible sound (about 20 kHz)

[SOURCE: IEC 60050-802:2011, definition 802-01-01]

3.46

ultrasonic physiotherapy equipment

equipment

equipment for the generation and application of **ultrasound** to a patient for therapeutic purposes

[SOURCE: IEC 60601-2-5:2009, definition 201.3.216, modified – The NOTE has been omitted]

4 List of symbols

a	geometrical radius of the active element of a treatment head
A_{BCS}	beam cross-sectional area
$A_{BCS(0,3)}$	beam cross-sectional area evaluated at 0,3 cm from the front face of the treatment head
$A_{BCS(z_N)}$	beam cross-sectional area evaluated at the position of the last axial maximum, z_N
A_{ER}	effective radiating area of a treatment head
A_{ERN}	nominal value of the effective radiating area of a treatment head
a_g	geometrical radius of the active element of a hydrophone
A_g	geometrical area of the face of a treatment head
a_{max}	maximum hydrophone effective radius defined by IEC 62127-3
A_o	unit area for a raster scan
arp	acoustic repetition period
b	minimum radius of a target for a radiation force balance
c	speed of sound in water
ERD	echo reduction
f_{awf}	acoustic working frequency
F_{ac}	conversion factor to convert $A_{BCS(0,3)}$ to A_{ER}
I_e	effective intensity
I_m	temporal maximum intensity
k	(= $2\pi/\lambda$) circular wave number

m	active area gradient
M_L	end-of-cable loaded sensitivity of a hydrophone
P	output power of a treatment head
P_{tm}	temporal-maximum output power
p_p	temporal-peak acoustic pressure
p_{sptp}	spatial-peak temporal-peak acoustic pressure
p_{max}	maximum rms acoustic pressure
p_{rms}	rms acoustic pressure
pms_t	total mean square acoustic pressure
$pms_t(z)$	total mean square acoustic pressure determined in the specific plane z
prp	pulse repetition period
prr	pulse repetition rate
Q	active area coefficient
R	ratio of the peak rms acoustic pressure to the rms acoustic pressure averaged over the beam cross-sectional area in a specified plane
R_{BN}	beam non-uniformity ratio
s	step size for a raster scan
$s(z)$	step size for raster scan in the specific plane z
s_n	normalized distance from the face of the transducer to a specified point on the beam alignment axis
U	end-of-cable voltage for a hydrophone
U_i	hydrophone signal for the i -th scan point
U_p	maximum value of the hydrophone voltage
z	distance from the face of the treatment head to a specified point on the beam alignment axis
z_j	distance from the face of the treatment head to the measurement plane (perpendicular to the beam alignment axis) of interest
z_N	distance of the last axial maximum from the face of the treatment head

z_p	distance of the peak rms acoustic pressure from the front face of the treatment head
λ	ultrasonic wavelength
ρ	density of water

Uncertainties are specified throughout this standard at the 95 % confidence level.

5 Ultrasonic field specifications

In addition to the general requirements specified in IEC 60601-1 and specific requirements specified in IEC 60601-2-5, manufacturers shall specify nominal values for the following parameters in the accompanying literature for each type of **treatment head**:

- **rated output power** (± 20 %);
- **effective radiating area** (A_{ERN}) of the **treatment head** (± 20 %);
- **effective intensity** at the same **equipment** settings as the nominal value of the **rated output power** (± 30 %);
- **acoustic working frequency** (± 10 %);
- **beam non-uniformity ratio** (R_{BN}) (± 30 %);
- **beam maximum intensity** (± 30 %);
- **beam type**;
- **pulse duration, pulse repetition period, duty factor** and the ratio of the **temporal maximum output power** to the **output power** for each modulation setting (± 5 %);
- **modulation waveform** for each modulation setting.

The numbers given in brackets are the tolerances defining the range of acceptable values for the results of either the type testing reference measurements specified in Clause 7 or the routine measurements specified in Clause 8. If the published tolerance requirement cannot be met, then the 95 % confidence level that is achievable should be reported. It shall then be demonstrated that the reported value, when incorporated with the tolerance so as to produce the 'worst case' value, remains within the range of acceptable values, as specified in IEC 60601-2-5, and on which guidance is provided in Annex A of this standard.

The temperature range shall be specified for the parameters specified above. The range of line voltages shall also be specified.

For **ultrasonic physiotherapy equipment** using a **treatment head** capable of operating at more than one nominal value of **acoustic working frequency**, the parameters listed above shall be specified for each nominal value of **acoustic working frequency**.

In addition, for **ultrasonic physiotherapy equipment** which can use an **attachment head**, the parameters listed above shall be specified for each combination of **attachment head** and **treatment head**.

NOTE This standard does not contain requirements relating to safety: these are covered in IEC 60601-2-5. Guidance on performance and safety can be found in Annex A of this standard.

6 Conditions of measurement and test equipment used

6.1 General

All measurements shall be undertaken in water under approximately free-field conditions at a temperature of $22\text{ °C} \pm 3\text{ °C}$.

If measurements are carried out at any other temperature, a test shall be undertaken to show that the results, determined in accordance with 7.6 and 8.6, are not dependent on the temperature at which the tests were undertaken.

Degassed water shall be used for the measurement of ultrasonic power, see 7.2. Degassed water is not essential for the **hydrophone** measurements, see 7.3.

NOTE Degassed water is essential to avoid cavitation when the physiotherapy units are operated at or near full **output power**. Information on preparation of water suitable for physiotherapy measurements may be found in IEC 61161, and in [3].

All measurements shall be made after the warm-up period specified by the manufacturer. If no such period is specified, a period of 30 min shall be used.

6.2 Test vessel

The test vessel used for all **hydrophone** measurements shall be large enough to allow the immersion of both the **treatment head** and the **hydrophone**. The tank size should conform to IEC 62127-1.

The relative position and angular orientation of the **treatment head** and **hydrophone** should be adjustable for the purposes of alignment in accordance with IEC 62127-1. Full degrees of freedom of movement of both may be provided, although the minimum requirement is that either the **treatment head** or the **hydrophone** should possess three independent degrees of translational movement. The measurements should be performed under free-field conditions. To achieve these conditions it may be necessary to line the walls of the test vessel as well as the mounts used to hold the **treatment head** and the **hydrophone** with absorbers or angled reflector(s) and absorber(s) of higher absorption and lower scatter. The free-field conditions will be met sufficiently when the overall echo is reduced by more than 25 dB. Various methods can be used to check the compliance for echo reduction of the tank lining materials used. One example to check the absorbing or scattering materials used is given below.

*Compliance for overall echo reduction of an acoustic absorber may be checked using the following procedure. Echo reduction should be measured at the **acoustic working frequency** of the **treatment head** under test using tone-burst **ultrasound**, with the acoustic absorber located in the **far-field** of the separately driven **ultrasonic transducer**. The resulting **hydrophone** signal (peak-to-peak or rms), produced by the reflection from the front surface of the acoustic absorber, U_{absorber} , is compared to that from a perfect planar reflector, $U_{\text{reflector}}$. The acoustic absorber and the perfect reflector should be aligned near normal to the **beam alignment axis** but angled so that the reflected signal can be intercepted by the **hydrophone**. The echo reduction (ERD, in dB) is calculated using:*

$$ERD = -20 \log_{10} \left[\frac{U_{\text{absorber}}}{U_{\text{reflector}}} \right] \quad (5)$$

A stainless steel reflector of minimum thickness 25 mm may be used to provide a good approximation to a completely reflecting surface.

Compliance of the test vessel to free-field conditions is checked by noting the invariance of the product $pms_{\perp} \times s^2$ (see 7.4.6) after completing the measurements specified in Clause 7.

NOTE For some **treatment heads**, **ultrasound** reflected back to the **treatment head** may affect **output power**, particularly in the case of coherent reflections from absorbers with planar smooth surfaces. In these instances, an improved approximation to free-field conditions may be obtained by using acoustic absorbers with textured surfaces.

6.3 Hydrophone

Measurements of **effective radiating area** shall use a needle **hydrophone**, with the active element made from either polyvinylidene fluoride (PVDF) or piezoceramic (PZT). The electrical signal from the **hydrophone** may be amplified for adequate measurement accuracy. The maximum effective radius of the **hydrophone** used for the measurements shall be a_{\max} so that:

$$a_{\max}/\lambda \leq 0,4 \quad (6)$$

NOTE 1 For more information on the use of **hydrophones** see IEC 62127-1.

NOTE 2 The influence of effective **hydrophone** radius on measurement is described in Annex H.

6.4 rms or peak signal measurement

The measured end-of-cable voltage, U , at the **hydrophone** shall be related to the **instantaneous acoustic pressure**, p , by:

$$p = UIM_L \quad (7)$$

where M_L is the **end-of-cable loaded sensitivity of the hydrophone**. However, in practice, the absolute values of the acoustic pressure are not required as the analysis of measured data throughout this standard is based on relative **hydrophone** measurements.

Subsequent reference to acoustic pressure will refer to the **rms acoustic pressure** for convenience. In fact, measurements may be based on either **rms** or **temporal-peak acoustic pressure** providing, whichever is used, all measurements are based on the chosen method of measurement.

NOTE Distortion caused by nonlinear propagation effects is usually negligible, in which case the peak acoustic pressure is proportional to the **rms acoustic pressure**. Therefore either the **rms acoustic pressure** or the **temporal-peak acoustic pressure** can be measured.

The linearity of the response of the combination of **hydrophone**, **hydrophone/amplifier** and the rms or peak detection system shall be determined and, if appropriate, corrections shall be made to the measured data.

*Compliance for linearity is checked using a separate **ultrasonic transducer** operating in tone-burst mode and measuring the signal received by the **hydrophone** and measuring system as a function of voltage excitation applied to the **ultrasonic transducer**.*

7 Type testing reference procedures and measurements

7.1 General

The procedures specified in 7.2 to 7.4 shall be used for the determination of type testing reference values for the parameters specified in 7.5

Any **ultrasonic physiotherapy equipment which includes** circuits that control the acoustic output of the **ultrasonic transducer** in response to changes in the acoustic impedance of the propagation medium should be configured so that the control circuitry is switched off.

7.2 Rated output power

Output power of the **ultrasonic physiotherapy equipment** shall be determined in accordance with IEC 61161. **Rated output power** shall be determined by setting all controls of the **equipment** to yield the maximum **output power**. To avoid cavitation, degassed water shall be used between the output face of the **treatment head** and the entrance of the power measurement system. Overall uncertainty of measurement expressed at the 95 % confidence level shall be determined (see 9.3) and should be better than ± 15 %. Measurements should be traceable to national measurement standards. The **absolute maximum rated output power** shall be determined from the sum of the **rated output power** and the overall uncertainty in the mean value of the measured **rated output power** and the maximum increase in the **rated output power** for a ± 10 % variation in the nominal line voltage. (See Annex F.)

7.3 Hydrophone measurements

The **treatment head** shall be set up in the test vessel in accordance with Clause 6.

Some **treatment heads** are known to produce reproducibly asymmetrical beams. In these cases the **treatment head** shall bear a mark on its housing identifying the direction yielding the maximum deviation of the value of the **beam cross-sectional area** determined from individual half line scans relative to the mean value, in both planes of measurement. One of the **hydrophone** translational axes shall be parallel to this direction (see 7.4.2).

All measurements of **effective radiating area** should be undertaken with the **equipment** set in **continuous wave** mode at intensities less than $0,5 \text{ W/cm}^2$ to avoid cavitation. For treatment heads with $ka \leq 20$ this intensity should be less than $0,2 \text{ W/cm}^2$. Degassed water is therefore not necessary for these measurements although care should be taken to ensure air bubbles are not present on the face of the **treatment head** or on the **hydrophone**.

NOTE 1 Measurements of **beam cross-sectional area** are performed at low powers to protect the needle **hydrophones** used. The validity of extrapolating these values to higher power levels more typical of therapeutic treatment is demonstrated in Annex G.

NOTE 2 **Treatment heads** with $a \leq 10$ mm, when compared with **treatment heads** of larger dimensions operating at similar **equipment** output settings, have been observed to produce higher **temporal-peak acoustic pressure** levels. For **treatment heads** with an **acoustic-working frequency** of 1 MHz or less, this increases the risk of cavitation occurring. The lower limit of $0,2 \text{ W/cm}^2$ for these small ka **treatment heads** minimizes this likelihood.

To reduce the likely effects of acoustic reflections on the received **hydrophone** signal, it is permissible to make **hydrophone** measurements with the **ultrasonic physiotherapy equipment** operating in tone-burst mode producing an **amplitude modulated wave**. If measurements are carried out in this way, it should be demonstrated that the derivation of the measured parameters from the **amplitude modulated wave** acoustic field are equivalent to those determined in the **continuous wave** case. The effect of making measurements in the **amplitude modulated wave** acoustic field case on the uncertainties in the nominal values of the parameters listed in Clause 5 should also be assessed.

The **beam alignment axis** of the **treatment head** shall be established in accordance with IEC 62127-1. The second plane surface (see 3.12) should initially be chosen as $A_{\text{ERN}}/(3\pi\lambda)$. If it is not possible to locate a single peak at or close to this distance, the larger distance of $2A_{\text{ERN}}/(\pi\lambda)$ should be chosen. If this latter distance is too large, locate another measurement plane sufficiently far from the first in order to establish reliably the **beam alignment axis**. Once aligned, an axial plot shall be performed along the **beam alignment axis** and the distance of the plane of **maximum rms acoustic pressure**, z_p , and the position of the last axial maximum, z_N , shall be determined.

The step size of the axial plot should be typically between 0,5 mm and 1,0 mm, and shall not be greater than 2 mm.

The **acoustic-working frequency** shall be determined with the **hydrophone** at a distance z_p from the **treatment head**.

With the **hydrophone** positioned at the same place, the **pulse duration**, **pulse repetition period** and **duty factor** shall be determined and the **modulation waveform** shall be recorded for the different modulation settings of the **equipment**. The quotient of the **temporal-peak acoustic pressure** to the **rms acoustic pressure** shall be determined for each modulation setting. The **temporal-maximum output power** shall then be determined using the **output power** determined from 7.2.

7.4 Effective radiating area

7.4.1 Effective radiating area, A_{ER} , of the **treatment head** shall be determined by undertaking a raster scan of the acoustic field in a plane perpendicular to the **beam alignment axis** at a distance of 0,3 cm from the output face of the **treatment head**, using a **hydrophone**. From this scan, the **effective radiating area** of the **treatment head** is derived from the **beam cross-sectional area**, A_{BCS} . The general requirements for raster scans are given in Clauses B.1 and B.2. The actual procedure for the reference measurements and the analysis of the results are given in 7.4.2 to 7.4.7. Under normal test conditions, the results using the test methods described should produce an overall uncertainty in the determination of **effective radiating area** (at the 95 % confidence level) of ± 10 %.

For the determination of the **beam non-uniformity ratio**, R_{BN} , under normal test conditions, the test methods should achieve a measurement uncertainty (at the 95 % confidence level) of less than ± 15 %.

7.4.2 With the **hydrophone** at distance z_p , the position of the **hydrophone** shall be adjusted in the plane perpendicular to the **beam alignment axis** to determine the **maximum rms acoustic pressure**, p_{max} , in the field.

This may be done by carrying out a raster scan over a limited region of the acoustic field or it may be done by manual translation.

7.4.3 The **beam cross-sectional area** shall be determined at 0,3 cm from the output face of the **treatment head**, and at the position of the last axial maximum, z_N . The analysis of the raster scans shall be carried out in accordance with Clause B.3. The analysis yields the **beam cross-sectional areas**, $A_{BCS}(0,3)$ and $A_{BCS}(z_N)$ and the **total mean square acoustic pressure**, pms_t , at each measurement plane.

7.4.4 The **active area gradient**, m , and the **active area coefficient**, Q , [$Q = m/A_{BCS}(0,3)$] shall be determined.

7.4.5 The **beam type** shall be determined from:

$Q > 0,1 \text{ cm}^{-1}$	divergent	
$- 0,05 \text{ cm}^{-1} \leq Q \leq 0,1 \text{ cm}^{-1}$	collimated	(8)
$Q < - 0,05 \text{ cm}^{-1}$	convergent	

7.4.6 The **effective radiating area**, A_{ER} , of the **treatment head** shall be determined as follows:

$$A_{ER} = F_{ac} A_{BCS}(0,3) = 1,333 A_{BCS}(0,3) \quad (9)$$

NOTE Studies have shown that physically unrealistic values for **treatment head effective radiating area** can occur when applying linear extrapolation procedures to scans carried out in four planes on small *ka* **treatment heads**. The analysis described above, in which the **effective radiating area** is determined from measurements made in a plane at a distance of 0,3 cm from the output face of the **treatment head**, produces physically realistic data.

7.4.7 The **beam non-uniformity ratio**, R_{BN} , shall be calculated from:

$$R_{BN} = \frac{p_{max}^2 A_{ER}}{pms_t \times s^2} \quad (10)$$

where

$$\overline{pms_t \times s^2} = \frac{1}{2} \left\{ [pms_t(0,3) \times s^2(0,3)] + [pms_t(z_N) \times s^2(z_N)] \right\} \quad (11)$$

NOTE Although p_{max} and pms_t are referred to as acoustic pressure or pressure-squared parameters, only their ratio is required for the determination of R_{BN} , hence the **end-of-cable loaded sensitivity of the hydrophone** is not required.

The product $pms_t \times s^2$ is related to the acoustic power and is calculated by summation of the pressure-squared values over the area of the raster scans in the plane at 0,3 cm from the **treatment head**, and also the plane at z_N . It should ideally be invariant with the distance from the **treatment head**.

7.4.8 The procedures given in 7.4.1 to 7.4.7 refer to measurements made on one **treatment head**. After measurements have been completed on the group of **treatment heads** in accordance with the sampling requirements of 9.1, mean values of the various parameters specified in 7.5 shall be determined.

7.5 Reference type testing parameters

For the purposes of reference type testing, values for the following parameters shall be determined and recorded:

- **rated output power**;
- **effective radiating area** (A_{ER}) of the **treatment head**;
- **effective intensity** (I_e) at the same **equipment settings** as the **rated output power**;
- **acoustic-working frequency** (f);
- the distance of the **peak r.m.s acoustic pressure** from the front face of the **treatment head**, (z_p);
- **beam non-uniformity ratio** (R_{BN});
- **beam type**;
- **pulse duration**, **pulse repetition period** and **duty factor** for each modulation setting;
- **modulation waveform** for each modulation setting.

NOTE This set of parameters could be used for the purposes of recording the performance of a single piece of **ultrasonic physiotherapy equipment**.

The values shall be the mean values based on sampling specified in 9.1. The overall uncertainty at the 95 % confidence level shall also be determined based on the methods specified in Annex J.

In addition, absolute maximum or absolute minimum values for certain parameters shall be determined as follows:

The **absolute minimum effective radiating area** shall be determined by subtracting the 95 % confidence overall uncertainty in the **effective radiating area** from the mean value of the **effective radiating area**.

The **absolute maximum beam non-uniformity ratio** shall be determined by adding the 95 % confidence overall uncertainty in the determination of the **beam non-uniformity ratio** to the mean value of the **beam non-uniformity ratio**.

7.6 Acceptance criteria for reference type testing

For the parameters listed below, the acceptance criteria for each **treatment head** shall be that the measured values plus and minus the 95 % confidence overall uncertainty in the measured values shall be entirely within the range defined by the nominal values and their tolerances specified in Clause 5. The parameters are as follows:

- **rated output power**;
- **effective radiating area** (A_{ER}) of the **treatment head**;
- **acoustic-working frequency**;
- **pulse duration, pulse repetition period** and **duty factor** for each **modulation setting**.

For **beam type**, the acceptance criterion shall be that the **beam type** shall be the same as the nominal **beam type** specified in Clause 5.

For **effective intensity** and **beam non-uniformity ratio**, acceptance criteria are specified in IEC 60601-2-5. Guidance on these parameters can be found in Annex A of this standard.

Compliance is checked by measurement in accordance with 7.2 to 7.4.

8 Routine measurement procedure

8.1 General

These procedures shall be used as the basis of tests that may be undertaken on a routine basis, possibly for each unit of **ultrasonic physiotherapy equipment**, but more typically for a certain percentage of the production. This could form the basis of good manufacturing practice or quality assurance procedures.

The routine tests specified here involve the determination of the values of certain acoustical parameters, which shall then be compared with the manufacturer's declared values (nominal values) and their tolerances, where appropriate, given in Clause 5.

8.2 Rated output power

The **rated output power** of the **equipment** shall be determined in accordance with 7.2.

NOTE Although not a requirement of this standard, ascertaining accuracy of indicated power is an integral part of calibration: see IEC 60601-2-5.

8.3 Effective radiating area

8.3.1 The **treatment head** is set up in the test vessel in accordance with Clause 6. However, alignment of the **treatment head** may be achieved by using a mount designed to hold the **treatment head** under test in an orientation similar to that used for the reference type testing. It is anticipated that an appropriate mechanical alignment device may be used that accepts the **treatment head** and always defines the orientation of the front face in relation to the translational axes of the **hydrophone**.

NOTE The aim here is to allow all **treatment heads** to be set up using a jig or alignment method in such a way that the orientation of each **treatment head** is the same as that used for the reference measurements.

8.3.2 A full axial plot of the acoustic pressure distribution shall be completed to locate the positions of z_p and z_N for each **treatment head**, such that p_{\max} may be determined.

8.3.3 The **beam cross-sectional area** shall be determined in the plane at a distance of 0,3 cm from the face of the **treatment head** by carrying out a raster scan as described in Subclause 7.4. The **beam cross-sectional area** at z_N shall also be determined, and may be derived from a raster scan in accordance with the requirements of Annex B, or by using four line or diametrical scans. The measurement and analysis procedures used for determination of **beam cross-sectional area** using diametrical scans shall be in accordance with Annex C.

Depending on whether a raster scan or line/diametrical scans are used, the procedures given in Annexes B or C shall be used to derive values for $A_{\text{BCS}}(0,3)$, $A_{\text{BCS}}(z_N)$ and the **total mean square acoustic pressure**, pms_t .

The **effective radiating area**, A_{ER} , shall be determined according to 7.4.

8.3.4 The **effective radiating area**, A_{ER} , may also be estimated on a routine evaluation basis through an alternative experimental method that uses a radiation force balance in conjunction with circular apertures, formed by an **ultrasound** attenuating material. An example of such an implementation, and a worked example of the calculations required to derive the **effective radiating area** from the measurements made using a range of aperture diameters, is described in detail in Annex I.

NOTE The value derived for the **effective radiating area** using the aperture technique should be considered as an approximation to the true **effective radiating area** that would be derived when carrying out the procedures described in 7.4.

8.4 Beam non-uniformity ratio

The **beam non-uniformity ratio**, R_{BN} shall be determined according to 7.4.6.

8.5 Effective intensity

The **effective intensity** shall be determined according to 3.22.

8.6 Acceptance criteria for routine testing

The range of **rated output power** defined by the measured **rated output power** plus and minus the 95 % confidence overall uncertainty for the routine measurement of **rated output power** (see 9.3), shall be entirely within the range of values defined by the manufacturer's nominal value for the **rated output power** and its tolerances specified in accordance with Clause 5.

Compliance is checked by measurement in accordance with 7.2.

The range of **effective radiating area** defined by the measured **effective radiating area** plus and minus the 95 % confidence overall uncertainty for the routine measurement of **effective**

radiating area, shall be entirely within the range of values defined by the manufacturer's nominal value of the **effective radiating area** and its tolerances specified in accordance with Clause 5.

Compliance is checked by measurement in accordance with 8.3.

The range of **effective intensity** defined by the measured **effective intensity** plus and minus the 95 % confidence overall uncertainty for the routine measurement of **effective intensity**, shall be entirely within the range of values defined by the manufacturer's nominal value of the **effective intensity** and its tolerances specified in accordance with Clause 5.

Compliance is checked by measurement in accordance with 7.2 and 8.3.

The value of the **beam non-uniformity ratio** plus the 95 % confidence overall uncertainty in the routine measurement of **beam non-uniformity ratio** shall be less than or equal to the nominal value of the **beam non-uniformity ratio** specified in accordance with Clause 5.

Compliance is checked by measurement in accordance with 7.4.7.

9 Sampling and uncertainty determination

9.1 Reference type testing measurements

The mean values for reference type testing specified in 7.5 shall be based on a sample batch of nominally identical units of the **ultrasonic physiotherapy equipment**.

9.2 Routine measurements

The routine measurements shall be undertaken as the basis of good manufacturing practice. Normally, they shall be undertaken as the basis for testing batch production or at any time when there may be reason to suspect changes may have occurred. Typically, they shall be undertaken on a certain percentage of production but, exceptionally, could be undertaken on each manufactured unit of **ultrasonic physiotherapy equipment**.

For the purpose of carrying out the Type A uncertainty evaluation (see Annex J) for routine measurements when full repeat measurements are impractical, partial repeat measurements may be carried out (by repeating those aspects of the measurement process which can be undertaken simply and quickly) and a prior knowledge for the type of measurement being undertaken then used to carry out an estimated Type A uncertainty evaluation.

NOTE An example of this would be to carry out two line scan measurements on a type of **treatment head**, and to use the outcome from a Type A uncertainty evaluation carried out previously on a raster scan on a **treatment head** of the same type to produce an overall uncertainty in **effective radiating area**.

9.3 Uncertainty determination

Where it is necessary to determine the 95 % confidence overall uncertainty of the measurement, or any parameter, for the purposes of this standard, normal uncertainty analysis and estimation methods shall be used (see Annex J for guidance).

Annex A (informative)

Guidance for performance and safety

A.1 General

The clauses in this annex reflect the established approach on acceptable values of a few safety related parameters

A.2 Rated output power

The **rated output power** should not vary by more than $\pm 20\%$ for variations of the mains voltage of $\pm 10\%$. Manual readjustment of the **equipment** for compliance with this requirement is not permitted.

*Compliance should be checked by measurement of the **rated output power** in accordance with 7.2 at 90 %, 100 % and 110 % of the rated value of the mains voltage. For example, if the physiotherapy unit has a rated mains voltage of 230 V, the **rated output power** should be checked at mains voltages of 230 ($\pm 10\%$) V.*

The term "rated" is defined in IEC 60601-1 as the "value assigned by the manufacturer to a quantity characteristic of the equipment". This means that when a manufacturer specifies a useable voltage on the back of a therapy unit, this is a "rated" value, and so from IEC 60601-2-5, the power output has to be checked for variation at 90 %, 100 % and 110 % of the declared value even when there is a range.

A.3 Effective intensity

The **absolute maximum effective intensity** should be less than or equal to $3,0 \text{ W/cm}^2$ [4].

*Compliance is checked by determination of the **absolute maximum rated output power** in accordance with 7.2 and **absolute minimum effective radiating area** in accordance with 7.4.*

A.4 Beam non-uniformity ratio

A.4.1 General

The **absolute maximum beam non-uniformity ratio** should be less than or equal to 8,0.

Compliance is checked by measurement in accordance with 7.4.

A.4.2 Rationale behind using a limiting value for the beam non-uniformity ratio (R_{BN})

The ultrasonic beam distribution produced by a therapeutic **treatment head** is non-uniform by nature. Besides this natural character, details of the construction and operation of the **treatment head** can produce regions of very high local pressure, also referred to as "hot spots". These may result in excessive heating in small regions of the tissue being treated, arising in potential harmful effects to the patient.

At the present time, therapeutic transducers are not designed to provide highly localized tissue treatment. Consequently, the transducers addressed in this standard are planar. The

characterization of focused transducers capable of generating high intensity beams which are being used in therapeutic applications will be the subject of future standards.

Alongside the safety aspects and the increased possibility of thermal injury, localized peaking of the pressure distribution resulting in a "hot spot" may also be considered as an adverse indicator of transducer quality. For these reasons, the therapist should have knowledge of the sound field distribution in order to apply therapeutic **ultrasound** judiciously. A measure of this non-uniformity is provided by the **beam non-uniformity ratio** (R_{BN}). The R_{BN} parameter represents the ratio of the highest intensity in the field to the average intensity, as indicated on the physiotherapy device.

If, as in a plane wave, the intensity is derived from the acoustic pressure alone, the ratio between the time-average intensity distribution (I_p) in a field and average intensity of the piston source (I_0) is given in Figure A.1 [5]. Following on from the previous discussion, this relation also represents the R_{BN} , and it follows that, on theoretical grounds, the maximum value will be 4. Even in the correct treatment where the true intensity (I) is given by the product of acoustic pressure and particle velocity, the maximum is 4 and will be found at one near-field length ($s_n = 1$ in Figure A.1). From the distance of about one transducer element radius, ($z/a=1$), back to the element itself, the maximum ratio will decrease typically to a value of the order of 2.

The actual determination of the R_{BN} may be performed using a **hydrophone**. In the following it will be shown that a calibrated **hydrophone** is not needed, which will simplify the method of determination.

In a plane wave approximation the relation between intensity and pressure (p) is given by: $I = p^2/\rho c$, where ρc is the characteristic acoustic impedance. This equation cannot strictly be used at distances closer than one transducer element radius of the **treatment head**. In most cases, the maximum pressure is found at greater distances than the **treatment head** radius and the error in using the expression, $I = p^2/\rho c$, results in relatively small inaccuracies as illustrated in Figure A.1.

As it may be assumed that the **hydrophone** output voltage is linearly related to the received acoustic pressure, the equation of the R_{BN} can be simplified as stated in this standard as follows:

The highest intensity in the beam, spatial-peak temporal-average, I_{spta} , is given by:

$$I_{spta} = \frac{U_p^2}{M_L^2 \rho c} \quad (A.1)$$

The quantity pms_t , used in the main body of this standard, is given by

$$pms_t = \sum_{i=1}^N \frac{U_i^2}{M_L^2} \quad (A.2)$$

and is known as the **total mean square acoustic pressure**. It represents a summation of the acquired voltages squared during the raster scan. Using pms_t , the spatial-average temporal-average intensity is given by:

$$I_{\text{sata}} = \frac{P}{A_{\text{ER}}} = \frac{A_o pms_t}{\rho c A_{\text{ER}}} \quad (\text{A.3})$$

The expression for the R_{BN} , given as the ratio $I_{\text{spta}}/I_{\text{sata}}$, may then be derived as:

$$R_{\text{BN}} = \frac{U_p^2 A_{\text{ER}}}{A_o(z_j) \sum_{i=1}^N U_i^2(z_j)} \quad (\text{A.4})$$

The denominator is related to an approximation of the total **output power**, derived by a summation of the intensities over the acoustic beam.

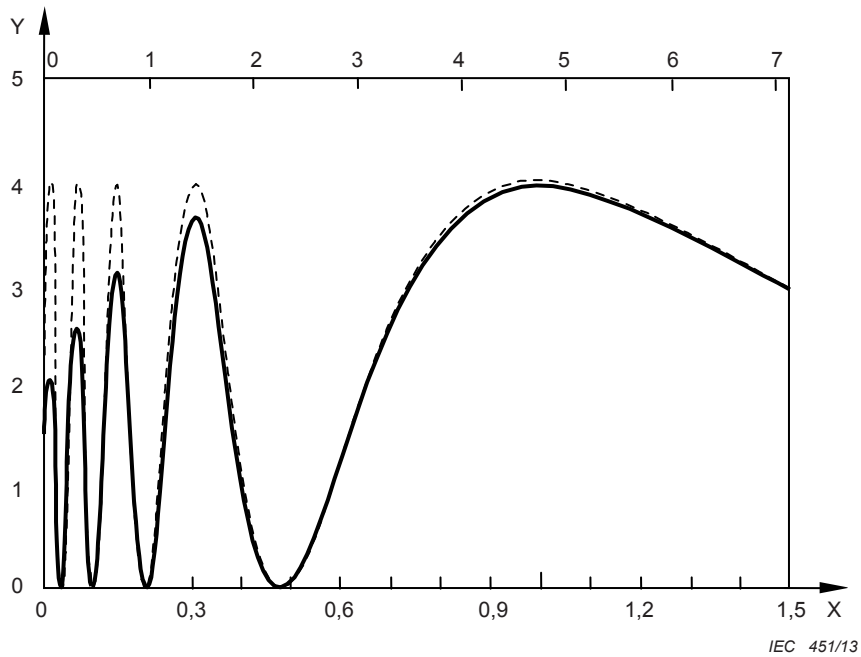
In the above equations, the parameters are as follows:

- U_p is the maximum value of the **hydrophone** voltage;
- U_i is the **hydrophone** voltage at the i -th point of measurement;
- M_L is the **end-of-cable loaded sensitivity of the hydrophone**;
- P is the acoustic power;
- pms_t is the **total mean square acoustic pressure**;
- ρ is the density of water;
- c is the speed of sound in water;
- A_o is the unit area of the scan ($A_o = s^2$ for a raster scan where s is the step size);
- N is the total number of measurement points in the scan;
- A_{ER} is the **effective radiating area**;
- z_j is the distance from the **treatment head** to the measurement plane of interest.

Figure A.2 illustrates a histogram in which the R_{BN} values calculated using the above equation are presented for 37 different **treatment heads**, along with the frequency with which these values occurred when the values of R_{BN} are separated into bands of 0,5. Normally, the R_{BN} appears to be in the range 3 to 7, but some transducers having a $R_{\text{BN}} > 8$ are shown and these may be considered to have a high R_{BN} .

The limiting value of eight has been identified in this standard for the following reasons:

- in **ultrasound** physiotherapy the treatment protocol (output, duration and frequency) used is based on an ultrasonic beam behaving normally, following theoretical expectations. Evaluating the dose for a treatment is currently difficult to define. Accordingly, a relaxation of the ideal R_{BN} value of four is appropriate. Relaxing the theoretical value of R_{BN} by a factor of 2 seems to be quite reasonable. As can be seen in Figure F.2, for normal behaving practical transducers, R_{BN} values less than eight can readily be attained;
- physiotherapists have no current requirement for a focused transducer. If a transducer is focused, the R_{BN} will easily exceed the value eight;
- from a quality point of view, taking the theory into account, there is no justification at all in having a R_{BN} greater than eight;
- it can be calculated that a R_{BN} value of 8,0 (limiting value) results in a maximum pressure at the maximum allowed output setting (3 W/cm²) in the range of 1 MPa, a spatial-peak temporal-peak intensity (I_{sptp}) of 48 W/cm² and a spatial-peak temporal-average intensity (I_{spta}) of 24 W/cm². It can be expected that higher values cause unwanted biological effects.



Key

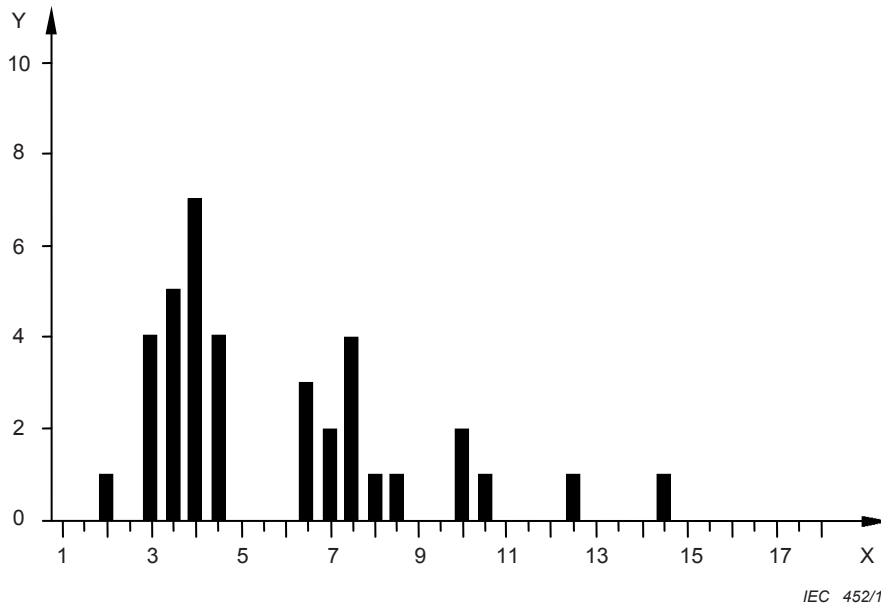
X: bottom axis: s_n

X: top axis: z/a

Y: $\frac{\bar{I}}{I_0}$ ————— ; $\frac{\bar{I}_p}{I_0}$ - - - - -

Figure A.1 – Normalized, time-averaged values of acoustic intensity (unbroken line) and of one of its plane-wave approximations (broken line), existing on the axis of a circular piston source of $ka = 30$, versus the normalized distance s_n , where $s_n = \lambda z/a^2$

NOTE In [5], the symbol "s" is used to describe the normalized distance. To avoid confusion with the raster scan step size definition used in this standard, the normalized distance symbol has here been changed to s_n .



Key

X: R_{BN}

Y: Number of transducers

Figure A.2 – Histogram of R_{BN} values for 37 treatment heads of various diameter and frequency

NOTE The R_{BN} value (in bands of 0,5) has been displayed against its frequency of occurrence.

Annex B (normative)

Raster scan measurement and analysis procedures

B.1 General

The determination of the **effective radiating area** of the **treatment head** for the purposes of reference measurements shall be performed using raster scans at 0,3 cm from the face of the **treatment head**. These procedures may also be used for routine measurements in accordance with Clause 8.

B.2 Requirements for raster scans

B.2.1 All raster scans shall be square grids with the central point on the **beam alignment axis** and in a plane perpendicular to the **beam alignment axis**. The scan shall not be a continuous motion but shall be performed in discrete steps with the values of rms or peak voltage measured at each point.

NOTE With the central point being on the **beam alignment axis**, there are necessarily an odd number of measured points on each line.

B.2.2 The boundaries of the raster scan shall be large enough to ensure that the signal level at any part outside the scanned boundary is at least 26 dB below the peak signal. However, for **treatment heads** having $z_N \leq 13$ cm, the level beyond the limits of the raster scan should be at least 32 dB below the peak signal.

NOTE Initial measurements are usually necessary to identify the size of the raster scan, and care needs to be taken to ensure that local diffraction minima do not lead to spuriously small scan areas.

B.2.3 The spacing between measurement points (step size) should be small enough such there are at least 31 measurements across the full width of the raster scan (the raster scan will therefore constitute a square grid of at least 31×31 points). See also B.3.2.

B.2.4 During the raster scan, the **hydrophone** may be scanned to a distance from the centre of the ultrasonic beam where no signal is obtained above the noise. To apply a correction to the integral of the square of the **hydrophone** signal to account for the contribution from the noise, the rms noise level U_n shall be subtracted from the measured signals in the following manner. If the **hydrophone** signal at each measurement point is U_i , then the **hydrophone** signal after correcting for the contribution from noise, U'_i is:

$$U'_i = (U_i^2 - U_n^2)^{1/2} \quad (\text{B.1})$$

The noise level shall be determined, as in IEC 62127-1, by moving the **hydrophone** to a position sufficiently far from the ultrasonic field that no direct acoustic signal is detected. In general, this shall be at a distance in the direction perpendicular to the **beam alignment axis** equal to at least twice the distance from the beam centre to the limit used for the raster scanning process.

B.3 Requirements for analysis of raster scan data

B.3.1 General

The two-dimensional array of data values obtained from the raster scan shall be analysed in the following way.

B.3.2 Total mean square acoustic pressure

The summation of the squares of the voltages obtained over the raster scan is related to the **total mean square acoustic pressure**, pms_t , given by:

$$pms_t = \sum_{i=1}^N (U'_i)^2 / M_L^2 \quad (\text{B.2})$$

where

N is the total number of points in the scan;

U'_i is the noise-corrected voltage (either peak or rms) of the i -th point in the scan;

M_L is the **end-of-cable loaded sensitivity of the hydrophone**.

NOTE The **end-of-cable loaded sensitivity of the hydrophone** has been introduced for convenience in Equation (B.1) to convert the measured voltage to acoustic pressure. However, due to cancellation, when pms_t is introduced into Equation (B.2), its absolute value is not required.

B.3.3 Calculation of the beam cross-sectional area, A_{BCS}

The values U'_i are sorted into a set in descending order (either rms or temporal peak) in the scan. A second summation shall be performed to find the value of n that satisfies the following two relationships:

$$\frac{1}{M_L^2} \sum_{i=1}^n (U'_i)^2 \leq 0,75 pms_t \quad (\text{B.3})$$

$$\frac{1}{M_L^2} \sum_{i=1}^{n+1} (U'_i)^2 > 0,75 pms_t$$

The value of A_{BCS} is then given by $A_o \times n$, where A_o is the unit area of the raster scan ($A_o = s^2$ where s is the distance between successive points in the scan, i.e. the step size). This procedure provides a value for the **beam cross-sectional area** in the measurement plane of interest.

For reliable determination of A_{BCS} , the number of points, n , included in the determination of A_{BCS} , should be at least 100.

Annex C (normative)

Diametrical or line scan measurement and analysis procedures

C.1 General

The determination of the **beam cross-sectional area** at a specified distance from the **treatment head** for the purposes of routine measurements in accordance with Clause 9 may be performed using diametrical or line scans. The term line scan will be used within this annex. If line scans are used then the procedures and analysis methods described below shall be used.

C.2 Requirements for line scans

C.2.1 The central or common point of the four line scans shall lie on the **beam alignment axis**. The relative angle of the scans shall be 45° and the four line scans shall divide the plane perpendicular to the **beam alignment axis** into eight equal areas.

C.2.2 The scan shall not be a continuous motion but shall consist of a series of discrete steps perpendicular to the **beam alignment axis** with the rms or peak voltage generated by the **hydrophone** being measured at each position.

C.2.3 The boundaries of each full-line scan shall be sufficiently large such that the **hydrophone** signal level at the edge of the line scan, relative to the peak level obtained, shall be at least 32 dB below the peak level.

C.2.4 The step size used during the line scan shall be sufficiently small such that the line scan consists of at least 50 points.

NOTE Each of the four line scans may be of different step size. Here, for ease of analysis, they will be assumed to be identical.

C.2.5 The noise level shall be determined, and measurements corrected for the influence of noise in accordance with B.2.4.

C.2.6 For simplicity, it will be assumed that the four line scans are of identical size, each containing N_1 measurements. This will be true for analysis of raster scan data but not generally true for line scan measurements.

C.3 Analysis of line scans

C.3.1 The individual line scans will be analysed in the following way.

NOTE In the steps described in C.3.1 to C.3.11, the symbols $[A]$ and $[B]$ refer to data arrays, and should not be interpreted as references to publications in the bibliography.

C.3.2 The four line scans shall be further sub-divided into a pair of radial scans (half-line scans). Each of these half-line scans consists of one-dimensional arrays, $[A]$, of data points sharing a common point on the **beam alignment axis** and having $(N_1 - 1)/2$ other points.

C.3.3 To calculate the **beam cross-sectional area** for each of the half-line scans, the one-dimensional sampling of the acoustic beam profile is transformed into a two-dimensional description of the beam assuming cylindrical symmetry.

C.3.4 For the measurement point which lies on the **beam alignment axis** (designated the $j = 0$ point) the contribution to such an area will be A_0 , given in centimetres squared, by:

$$A_0 = \frac{\pi s^2}{4} \quad (\text{C.1})$$

where s is the step size (for diagonal radial scans derived from raster scan measurements the step size will be $s\sqrt{2}$).

C.3.5 For all of the other elements of the half-line scan, from $j = 1$ to $(N_1 - 1)/2$, the contribution to the scan area will be annuli of thickness s . For the j -th measurement the corresponding annulus area, A_j , will be given by the expression:

$$A_j = \pi s^2 \left[\left(j + \frac{1}{2} \right)^2 - \left(j - \frac{1}{2} \right)^2 \right]$$

$$A_j = 2\pi j s^2 \quad (\text{C.2})$$

C.3.6 To calculate the beam cross-sectional area, the area of each of the annuli from $j = 1$ to $(N_1 - 1)/2$ shall be broken down into multiples of the smallest unit area A_0 . By dividing A_j given in Equation (C.2) by A_0 given in Equation (C.1), it may be seen that the j -th annulus is comprised of n_j units of the smaller area, such that:

$$n_j = 8j \quad (\text{C.3})$$

C.3.7 Using this expression, the original one-dimensional array representing the line scan shall be transformed into a new one-dimensional array $[B]$ the elements of which are shown in Table C.1.

Table C.1 – Constitution of the transformed array $[B]$ used for the analysis of half-line scans

Measurement point	Voltage squared U_j^2	Number of elements in array $[B]$ of value U_j^2
$j=0$ (point on beam alignment axis)	U_0^2	1
$j = 1$ (first point off-axis)	U_1^2	8
$j = 2$ (second point off-axis)	U_2^2	16
•	•	•
•	•	•
•	•	•
$j = (N_1 - 1)/2$ (last point in scan)	$U_{(N_1-1)/2}^2$	$4(N_1-1)$
NOTE The j -th ($j > 0$) point in the half-line scan array $[A]$ is represented in the new array by $8j$ elements of the original voltage-squared values. The new array will contain N_1^2 elements.		

C.3.8 In a similar manner to the analysis undertaken using the raster scan data in B.2.4, the rms noise level U_n shall be subtracted from each line scan data point, to account for the contribution of noise. If the **hydrophone** signal at each point in the line scan is U_j , then the **hydrophone** signal after correcting for the contribution from noise, U'_j is:

$$U'_j = (U_j^2 - U_n^2)^{1/2} \quad (\text{C.4})$$

C.3.9 To evaluate the **beam cross-sectional area** the **total mean square acoustic pressure**, pms_t , of the half-line scan is required. This is given by:

$$pms_t = \frac{1}{M_L^2} (U_0')^2 + \frac{1}{M_L^2} \sum_{j=1}^{(N_L-1)/2} 8j (U_j')^2 \quad (\text{C.5})$$

C.3.10 The new array $[B]$ is sorted into descending order and a second summation performed as described in Equations (B.3), leading to the determination of the value of n .

NOTE Performing the sorting process on the original n values will lead to the same result if the correct weighting is applied during the summation process.

C.3.11 The **beam cross-sectional area**, A_{BCS} , of the half-line scan is given by $A_{BCS} = \frac{n\pi s^2}{4}$ where s is the step size.

C.3.12 The analysis shall be completed for all eight half-line scans and the results averaged to determine the mean value along with the standard deviation.

In the measurement plane z , the standard deviation, σ , of the distribution of **beam cross-sectional areas** for the eight half-line scans shall be determined from:

$$\sigma^2 = \frac{1}{7} \sum_{j=1}^8 \left(A_{BCSj}(z) - \overline{A_{BCS}(z)} \right)^2 \quad (\text{C.6})$$

where

$A_{BCSj}(z)$ is the **beam cross-sectional area** derived from the j -th line scan in the plane at distance z ;

$\overline{A_{BCS}(z)}$ is the mean value calculated from the eight line scans.

Annex D (informative)

Rationale concerning the beam cross-sectional area definition

In physiotherapy, the ultrasonic intensity levels used are relatively high. They are in the range where adverse biological effects have been observed in addition to those which are intended to be beneficial. It is therefore important that the operator knows the particular ultrasonic intensities being delivered by the **ultrasonic physiotherapy equipment**. In principle, this is achieved by the **ultrasonic physiotherapy equipment** having a front-panel indication of output power and intensity and these indications have to be reliable and accurate.

Since the most appropriate indication of **effective intensity** is a spatial average value derived by dividing the **output power** by an area, the use of an intensity indication implies the need for a well-defined area. This area should be seen as that part of a plane – at or close to – the applicator, through which almost all of the **ultrasound** power passes and is defined in this standard as the **effective radiating area**.

A **treatment head** used in **ultrasonic physiotherapy equipment** contains an **ultrasonic transducer** consisting of a piezoelectric active element which is often mounted on a metal face plate. Since this piezoelectric element does not vibrate with the same amplitude over its entire surface, it is not sufficient to specify beam area as the geometric area of the piezoelectric element. The actual **effective radiating area** is determined directly from **hydrophone** measurements.

The parameter **beam cross-sectional area**, as defined in this standard, is the area determined using the **hydrophone** and represents an intermediate step in the process of deriving the **effective radiating area**. The method specified in this standard represents the outcome of studies, based on actual measurements and theoretical calculations, to provide a useful definition and a reliable measurement method [1, 2, 6, 7, 8].

Any method used to determine the **beam cross-sectional area** should not be too sensitive to local inhomogeneities within the ultrasonic beam. During an evaluation of **ultrasonic physiotherapy equipment** [9] it was demonstrated that measuring the **beam cross-sectional area** in accordance with the definition used in the US FDA standard (which takes the contribution at a distance of 5 mm of all areas where the intensity is greater than 5 % of the maximum intensity in the plane) [10] produces, for certain ultrasonic beams, very inaccurate results.

The pressure distribution of a typical **treatment head** with a small geometric radiating area, having a ka of approximately 17, where k is equal to $2\pi/\lambda$ and a is the geometrical radius of the active element of the **ultrasonic transducer** used in the **treatment head**, is given in Figure D.1. In this distribution the maximum pressure decreases rapidly with distance from the face of the **treatment head**.

To investigate the effect of the beam characteristics on the defined areas, the limit levels, 5 % of the maximum intensity for the FDA definition and 75 % of the sum of the **total mean square acoustic pressure** for the IEC definition, are explored more widely. Figure D.2 shows the variation of **beam cross-sectional area** measurements (IEC) and **effective radiating area** measurements (FDA) with the limit levels for a set of measurement planes close to 5 mm from the face of the **treatment head**. Results for five measurement planes are shown, the total separation from the 5 mm plane being $\pm 0,5$ mm with a spacing of 0,25 mm between measurement planes. Figure D.2 shows that the **effective radiating area**, following the FDA definition, is very sensitive to the measurement position. It also shows that if another limiting level is taken, greater than the 5 % required in the FDA definition [10], this results in an increased sensitivity of the **effective radiating area** to small errors in the position of the measurement plane, i.e. the slopes of the curves shown in Figure D.2 for the FDA definition

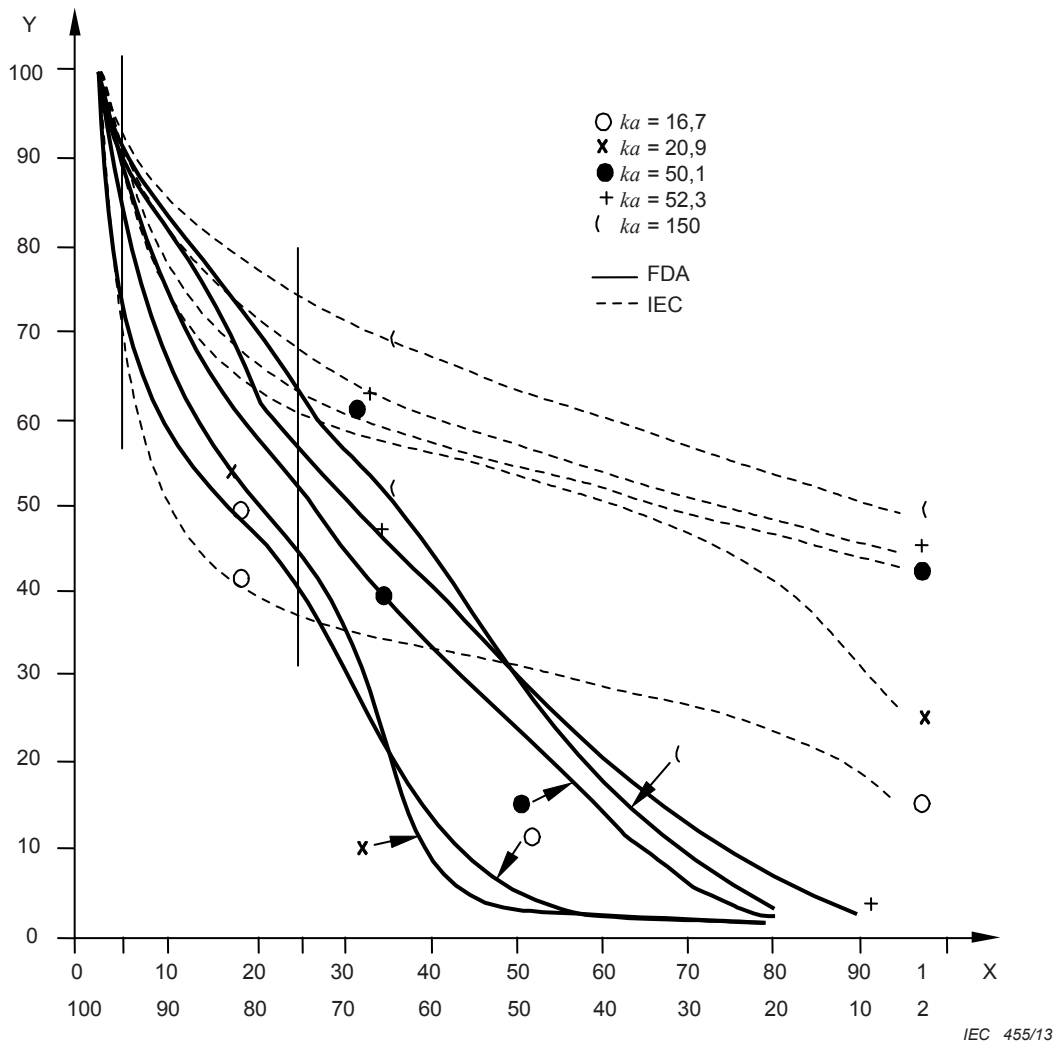
are greater than those for the IEC definition. The smooth character of the curves for the IEC definition is also evident from Figure D.2.

Treatment heads used in physiotherapy are of various frequencies and diameters and may typically have ka values in the range between 17 and 150. In Figure D.3, the typical behaviour of the **beam cross-sectional area** as a function of different limit levels is plotted for some **treatment heads** with ka values in this range. Although the ka values for the different **treatment heads** differ considerably, the shape of the curves seems to be similar.

Instabilities in the pressure measurement, e.g. caused by thermal drift or inhomogeneities in the water path, can be seen as instabilities in the limit level. The effect of this instability in the pressure measurement on the calculated **beam cross-sectional area** is complex and depends strongly on the beam shape. The **effective radiating area** derived from the FDA analysis is very sensitive to these instabilities as it depends critically on the reliable evaluation of a single maximum level. This is not the case using the IEC definition, which exhibits a relative insensitivity to the peak value acquired in the scan. This is demonstrated in Figure D.3 from the 75 % limit used in this standard.

These experimental conclusions are confirmed by theoretical calculations. Calculations carried out using a circular piston source with radius $a = 4\lambda$, which represents a relatively small transducer, and a point receiver, are presented in the series of curves making up Figure D.4. These depict the variation of **effective radiating area** and **beam cross-sectional area** for increasing distances away from the **treatment head**. The **hydrophone – treatment head** separation has been normalized to the acoustic wavelength which means that the whole range of frequencies currently used in physiotherapy is presented. The **beam cross-sectional area** value (**effective radiating area** for the FDA definition) has been normalized relative to the actual element size. Although the **beam cross-sectional area** following the new definition shows some variation with normalized distance, it is clearly less dependent on the beam characteristics than the **effective radiating area** calculated from the FDA definition [10].

In other calculations presented in Figure D.5, the normalized **beam cross-sectional area** is calculated as a function of ka . The range of ka values used covers the whole range of sizes of **ultrasonic transducers** used in the **treatment heads** of **ultrasonic physiotherapy equipment**. Although the curves shown in Figure D.5 only present results obtained at distances of 5 mm and $2a$ from the face of the **ultrasonic transducer**, the behaviour is representative of calculations performed at other distances. From Figure D.5 the same general conclusion can be drawn as from Figure D.4: the **beam cross-sectional area** definition as specified in this standard is less dependent on details of the **ultrasound** beam profile than the definition used in the FDA standard [10].



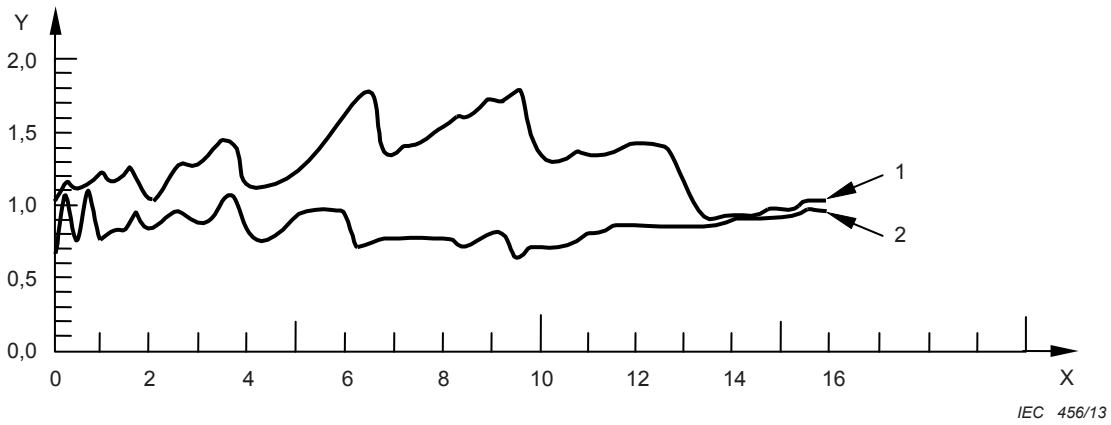
Key

X limit %, 1 following FDA standard
 2 following IEC standard

Y relative value of A_{BCS}

$z = 0,5 \text{ cm}$

Figure D.3 – Normalized values of beam cross-sectional area for IEC and FDA limit values for five transducers of different ka values



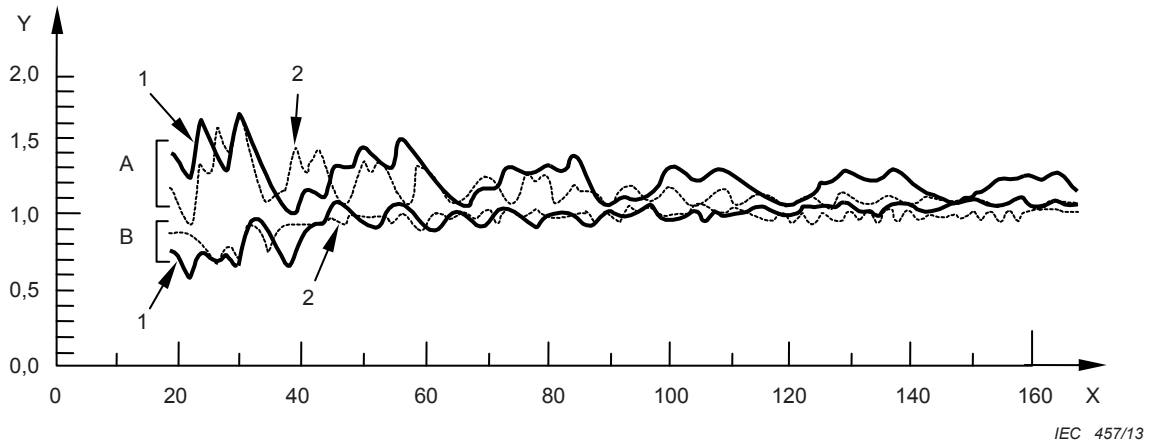
Key

X z/λ

Y normalized beam cross-sectional area A_{BCS} , 1 following FDA standard, 2 following IEC standard

NOTE The distance, z , and the **beam cross-sectional area** have been normalized to the acoustic wavelength and true element area, respectively.

Figure D.4 – Range of values of the beam cross-sectional area (A_{BCS}) with distance from the face of the treatment head



Key

X ka

Y normalized beam cross-sectional area A_{BCS}

A following FDA standard

B following IEC standard

1 at $z = 5 \text{ mm}$

2 at $z = 2a$, where a is the geometrical radius of the active element of the **ultrasonic transducer**

NOTE Calculations have been carried out at distances of 5 mm and $2a$ from the **treatment head**.

Figure D.5 – Range of values of the normalized beam cross-sectional area (A_{BCS}) with transducer ka

Annex E (informative)

Factor used to convert the beam cross-sectional area (A_{BCS}) at the face of the treatment head to the effective radiating area (A_{ER})

This standard requires the **effective radiating area**, A_{ER} , to be derived from the **beam cross-sectional area** close to the face of the **treatment head**, $A_{\text{BCS}}(0,3)$. The **beam cross-sectional area**, $A_{\text{BCS}}(z)$, is defined as the smallest area contributing 75 % of the total **mean square acoustic pressure**.

When a simplified sound field model with a **collimated beam** and constant pressure distribution over its cross-section perpendicular to the sound field axis is used, the definitions lead to the following relation:

$$A_{\text{ER}} = 1,333 A_{\text{BCS}}(0) = 1,333 A_{\text{BCS}}(z) \quad (\text{E.1})$$

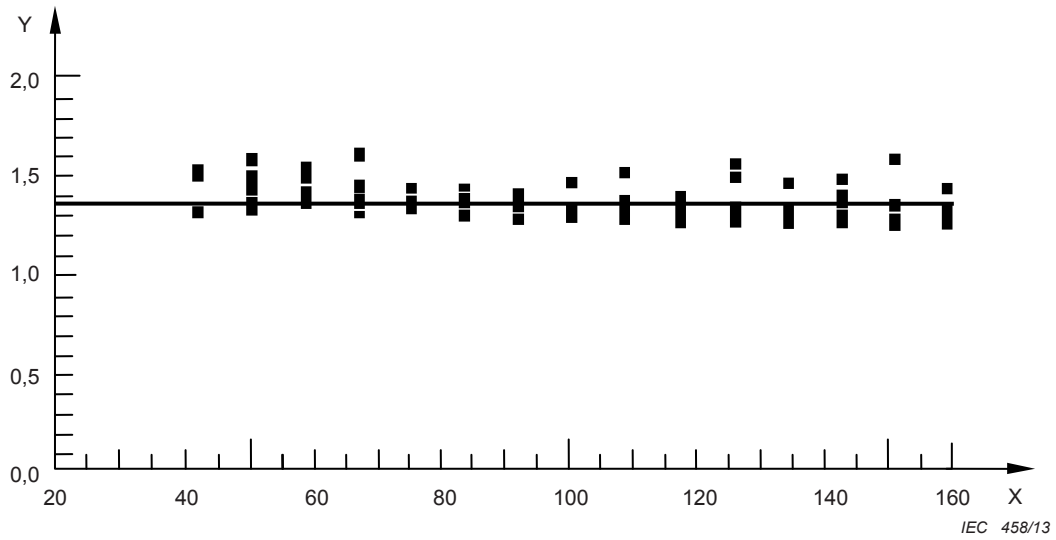
From the physical point of view, it can be expected that the simplified model is useful for values of ka that are not too small ($k = 2\pi/\lambda =$ circular wavenumber, $a =$ geometrical radius of the active element of the **treatment head**). With smaller values of ka , diffraction effects will cause the sound beam to spread and consequently the simplified model will fail.

To obtain a realistic estimate of the conversion factor needed (termed F_{ac} in what follows), numerical simulations were performed using a circular piston source, finite size receivers of radius 0,25 mm and 0,5 mm, at frequencies of 1 MHz, 2 MHz and 3 MHz. For transducers of small effective radii (< 4 mm), and particularly at low frequencies, the beam will diverge to such an extent that no realistic estimate of the **effective radiating area** may be made. In practice, because no physiotherapy **treatment heads** exhibit effective radii smaller than 4 mm, the calculations have been limited to radii ≥ 4 mm. In the computer simulations, the ka product covers the range from approximately 16 to 160. The calculations follow exactly the definitions mentioned above.

Figure E.1 (from [1]) shows the distribution of F_{ac} in the range $ka \approx 40$ to $ka \approx 160$. The mean value calculated is $F_{\text{ac}} = 1,354$, which is very close to $F_{\text{ac}} = 1,333$, valid for the simplified sound field model.

A study has been carried out on a large sample of small ka **physiotherapy treatment heads** [9], and has defined the approach described in 7.3 for determining the **effective radiating area**, whereby raster scans are carried out in a plane at a distance of 0,3 cm from the **treatment head**. Results from the study show that this approach produces $A_{\text{BCS}}(0,3)$ values which may be multiplied by the same F_{ac} value (1,354) to derive the A_{ER} , independent of the ka value of the **treatment head**.

The numerical investigations performed in the above studies did confirm agreement, within the uncertainty achieved, with the value obtained using the simplified sound field model. For the sample size studied (66 points), the standard deviation of the mean value is approximately 0,09. The deviation of the mean value ($F_{\text{ac}} = 1,354$) from the value obtained using the simplified sound field model ($F_{\text{ac}} = 1,333$) was less than this standard deviation. To avoid that, possibly large, uncertainties need to be taken into account in the determination of the **effective radiating area** it has been agreed to use $F_{\text{ac}} = 1,333$ without the need to consider an uncertainty contribution for this fixed value.



Key

X ka
Y F_{ac}

NOTE The solid line represents the mean value, $F_{ac} = 1,354$.

Figure E.1 – Conversion factor F_{ac} as a function of the ka product for ka product between 40 and 160

Annex F (informative)

Determining acoustic power through radiation force measurements

This standard requires the declaration of the **rated output power**. As stated in 7.2, the measurement of the **output power** of the **ultrasonic physiotherapy equipment** is to be carried out in accordance with IEC 61161, where the use of a radiation force balance is recommended. Radiation force measuring devices are easy to handle and to calibrate.

The most important part of a radiation force device is the target. It must be large enough to cover the whole ultrasonic field. Subclause A.5.3 of IEC 61161: 2013 gives formulae for calculating the minimum value of the target radius b as a function of the target distance z , the wavelength and a_1 , the effective radius of the active element of the **treatment head**. The formulae given in IEC 61161: 2013 are based on theoretical calculations using a piston field approach [6]. Table F.1 shows some typical results. The target radius should be understood as the radius of the largest cross-section of the target, and the target distance as the distance of that cross-section from the **treatment head**.

It should be noted that the results given apply to a piston field. It may be that the **treatment head** under test does not behave like a piston. It is therefore recommended to also make use of the information contained in the measurement results of the **beam cross-sectional area**, $A_{BCS}(z)$. An equivalent radius b_{eq} can be determined from:

$$b_{eq}(z) = (A_{BCS}(z)/\pi)^{1/2} \quad (F.1)$$

If $2 b_{eq}$ is larger than the value of b determined in accordance with IEC 61161 and Table F.1, then $2 b_{eq}$ is used as the minimum value for the target radius.

Bubbles in water act as scatterers of ultrasonic waves and can lead to errors in measurement. It is therefore important to use only degassed water in measurements on physiotherapy devices, and always to make sure that (a) no bubbles are present on the transducer and target surfaces and (b) no bubbles appear during the measurement as a consequence of the degassing potential of high-intensity **ultrasound** (see IEC 61161, IEC/TR 62781 and bibliographic reference [3]).

Although **output power** values are often in the watt range for **ultrasonic physiotherapy equipment**, in order to cover the full range of **output power** measurements for compliance with this standard, a balance with a sensitivity as low as 15 mW may be required. One problem for measurements at higher power ranges may be the stability of the target position during the measurement. While an absorbing target is not affected by lateral radiation force components and a concave reflector is self-centring, a convex reflector may be de-centred by the radiation force. This effect depends mainly on the magnitude of the ultrasonic **output power**, on the target weight and the kind of target suspension (see 5.6 of IEC 61161: 2013).

Table F.1 – Necessary target size, expressed as the minimum target radius b , as a function of the ultrasonic frequency, f , the effective radius of the treatment head, a_1 , and the target distance, z , calculated according to A.5.3.1 of IEC 61161: 2013 (see [6])

Effective radius a_1 of the treatment head cm	Ultrasonic frequency f MHz	Target distance cm	Minimum target radius cm
0,5	1	0,5	0,77
		2,0	1,89
		4,0	3,54
		6,0	5,23
1,5	1	0,5	2,25
		2,0	2,25
		4,0	2,46
		6,0	3,05
0,5	3	0,5	0,75
		2,0	1,02
		4,0	1,67
		6,0	2,36
1,5	3	0,5	2,25
		2,0	2,25
		4,0	2,25
		6,0	2,25

Annex G (informative)

Validity of low-power measurements of the beam cross-sectional area (A_{BCS})

Measurements of the **beam cross-sectional area** made using **hydrophones** require the **treatment head** to be operated in **continuous** wave mode at intensities of $0,5 \text{ W cm}^{-2}$ or less (see 7.3). Measurements at low powers are required to prevent damaging the probe **hydrophones** used. Table G.1 (from [1]) presents the verification that values of **beam cross-sectional area** obtained at low powers are valid at higher operating powers employed for physiotherapy treatments. The table illustrates measurements made using a polyvinylidene fluoride (PVDF) membrane **hydrophone** of the differential output type for various powers indicated by the physiotherapy unit used. The **treatment heads** were both 1,5 MHz transducers of diameter 2,8 cm; A operated normally whilst B was characterized as a "hot spot" transducer exhibiting a large axial peak at 2,9 cm. The measurements for the second transducer were made in this plane.

**Table G.1 – Variation of the beam cross-sectional area ($A_{BCS}(z)$)
with the indicated output power from two transducers**

Indicated power W	Transducer A ¹ $A_{BCS}(z)$ cm ²	Transducer B ² $A_{BCS}(z)$ cm ²
1,25	3,54	2,99
5,00	3,50	2,92
7,50	3,52	2,80
10,0	3,48	2,79
12,5	3,51	2,80
15,0	3,49	2,87
1 1,5 MHz; diameter 2,8 cm; A_{BCS} determined at 4,0 cm.		
2 1,5 MHz; diameter 2,8 cm; A_{BCS} determined at 2,9 cm; the distance of the maximum rms acoustic pressure for this "hot spot" transducer.		

The results presented in Table G.1 show that the variation of $A_{BCS}(z)$ with power is small, no more than a few per cent.

This invariance of the **beam cross-sectional area** with **output power** may not be valid for some defective **treatment heads**, particularly those where heating occurs, although it is anticipated that such cases will be rare.

Annex H (informative)

Influence of hydrophone effective diameter

Most **hydrophones** currently available commercially have active elements of diameter in the range 0,2 mm to 1,0 mm. At megahertz frequencies the accuracy of ultrasonic field measurements may be compromised by spatial averaging of the acoustic pressure over the active element. IEC 62127-1 provides the following criterion for the maximum permissible **hydrophone** radius, a_{\max} , which may be used in any measurement situation:

$$a_{\max} = \frac{\lambda}{8} \left(1 + \frac{z^2}{a_1^2} \right)^{1/2} \quad (\text{H.1})$$

where

λ is the acoustic wavelength;

z is the distance from the **treatment head** to the measurement plane;

a_1 is the effective radius of the active element of the **treatment head**.

The procedures specified in this standard to accurately determine the **effective radiating area** of a **treatment head** requires measurements close to the face of the **treatment head** and will result in the frequent violation of this criterion. Equation (H.1) relates strictly to the measurement of peak pressures and is of relevance for reliably determining the **beam non-uniformity ratio** (R_{BN}). Due to the greater accuracy required of measurements of the **effective radiating area**, it is important to establish the effect of violation on measurements of $A_{\text{BCS}}(z)$ and A_{ER} .

Measurements made on a 3 MHz **treatment head** of diameter 2,4 cm using various **hydrophones** of different active element radius are presented in Table H.1 (after [4]). Measurements were made using ceramic **hydrophones** of active diameter 0,6 mm and 1,0 mm, and a 4 mm diameter PVDF **hydrophone** of the membrane type (the latter was used as a ceramic **hydrophone** with 4 mm active element was not available). For measurements at $z = 1,0$ cm, according to Equation (H.1), these **hydrophones** are strictly too large by factors of 4, 6,5 and 26 respectively. The results displayed in Table H.1 indicate agreement between measurements of $A_{\text{BCS}}(z)$ of between 1 % and 3 %.

With currently utilized physiotherapy **treatment head** frequencies and diameters, the most stringent test of IEC 62127-1 criterion is for measurements close ($z = 1,0$ cm) to large diameter, 3 MHz **treatment heads**. Even in this case, violation will be by no more than a factor of six to seven for a 1 mm active element diameter **hydrophone**.

Table H.1 also presents values of the ratio of the peak pressure squared to the average pressure squared over the **beam cross-sectional area** in the plane at distance z , where z varies from 1,0 cm to 8,0 cm (this ratio is denoted by R in Table H.1), which indicates that even in the presence of strong violation for measurements using the 4 mm diameter **hydrophone**, differences are no more than 20 %. These results can be directly related to the choice of the diameter of the active element of the **hydrophone** for the purposes of determining R_{BN} . However, these findings should be treated with some caution. Certain **treatment heads** exhibit "hot spots" characterized by beam widths (– 6 dB) of the main peak as small as 2 mm to 3 mm. Use of a **hydrophone** as large as 4 mm would underestimate the true value of the R_{BN} .

Due to the concern over R_{BN} measurement accuracy, the criterion used in 6.2 of this standard will allow valid measurements of the **beam cross-sectional area** to be made with a 1,0 mm **hydrophone** on currently available **ultrasonic physiotherapy equipment** operating up to 3 MHz. For **ultrasonic physiotherapy equipment** operating above 3 MHz, a **hydrophone** of diameter less than 0,6 mm is specified. These **hydrophones** will, in most practical circumstances, allow measurements of **effective radiating area** and **beam non-uniformity ratio** to be made reliably.

Table H.1 – Comparison of measurements of the beam cross-sectional area ($A_{BCS}(z)$) made using hydrophones of geometrical active element radii 0,3 mm, 0,5 mm and 2,0 mm

Hydrophone mm	Measurement	Treatment head-hydrophone separation, z cm			
		1,0	2,0	4,0	8,0
A ceramic $a_g = 0,3$	$A_{BCS}(z)$ cm ²	2,00	1,97	2,01	2,07
	R^a	1,55	1,57	1,68	2,69
C ceramic $a_g = 0,5$	$A_{BCS}(z)$ cm ²	1,93	1,96	1,99	2,08
	R^1	1,68	1,69	1,60	2,26
PVDF bilaminar membrane $a_g = 2$	$A_{BCS}(z)$ cm ²	2,01	2,00	2,02	2,10
	R^a	1,95	1,91	2,04	2,33

NOTE Measurements were made on a 3 MHz **treatment head** at four distances.

^a The R values have been derived using the averaged p^2 value evaluated in the specified measurement plane.

Annex I (informative)

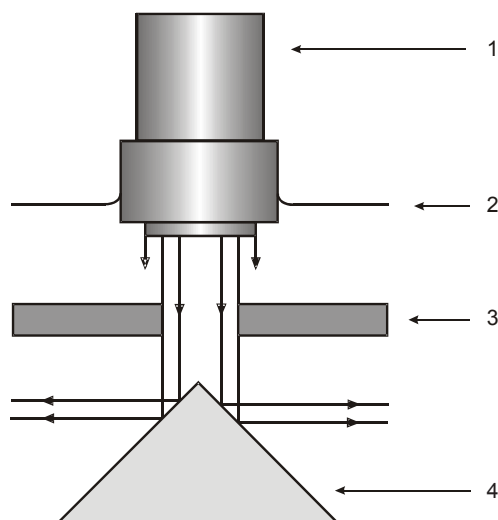
Effective radiating area measurement using a radiation force balance and absorbing apertures

I.1 General

This annex provides details of a method for determining the **effective radiating area** (A_{ER}) of physiotherapy **treatment heads** that utilizes a radiation force balance and a series of masks for measuring its ultrasonic output power. Such approaches are described in [11] and [12]. Radiation force balances are widely available within hospitals and it is anticipated that this method could be applied as simple method of "in-service" checking of the **effective radiating area**. The method described in this annex is not intended as a replacement for the procedures described in Clause 7, which represent the reference method for determining **effective radiating area**.

I.2 Concept of aperture method

The concept behind the aperture method is illustrated schematically in Figure I.1, where an absorbing aperture is shown interposed between the **treatment head** and the target of the radiation force balance, which in this case is of the convex conical reflecting type (an absorbing target could also be used). The apertures are circular holes cut within an acoustically absorbing material, which, when placed in front of a **treatment head**, allow the effective radiating surface of the **treatment head** to be selectively reduced. The resulting reduction in power is measured using the radiation force balance. By masking off areas of the **ultrasound** beam using a range of apertures, the spatial distribution of the transmitted power can be sampled. The aim of the measurements, in combination with the data analysis presented in Clause I.5, is to compute the area through which the majority of power is transmitted, thus deriving a value for the **effective radiating area** or A_{ER} . In the remainder of this annex, the term "aperture" will be used to represent the mask and the circular hole cut therein.



IEC 459/13

Key

- 1 treatment head
- 2 water surface
- 3 aperture mask (I.3.2)
- 4 radiation force balance target

NOTE Figure I.1 portrays a "vertical" arrangement of radiation force balance with a reflecting target, although alternative arrangements may be used (IEC 61161).

Figure I.1 – Schematic representation of aperture measurement set-up

I.3 Requirements for the aperture method

I.3.1 Radiation force balance

Aside from the geometrical considerations of the need to be able to interpose the absorber layer forming the aperture between the **treatment head** and the radiation force balance target, the key aspect of the radiation force balance relating to its performance in measuring **effective radiating area** lies in its reproducibility and resolution, which should ideally be $\pm 0,01$ W.

I.3.2 Apertures

I.3.2.1 Acoustic properties of aperture material

It is important that any material used to fabricate the apertures minimally perturbs the **output power** generated by the **treatment head** under test. Its acoustic properties should be such that the

- reflection loss of **ultrasound** from the surface of the apertures is better than – 30 dB;
- transmission loss of **ultrasound** through the material is less than – 25 dB.

Both of these properties refer to the particular frequency of operation of the **treatment head**.

The aperture mask materials may be made from single or multi-layers and can be manufactured from absorbing rubbers.

Compliance can be checked using techniques similar to those described in 6.2.

I.3.2.2 Aperture diameters

Nominal aperture diameters in the range 0,4 cm to 3,0 cm allow measurements of **effective radiating area** to be made on the majority of commercially available physiotherapy **treatment heads**. The actual diameters should be uniformly cylindrical to, and known, to $\pm 0,01$ cm.

I.3.2.3 Lateral extent of aperture mask material

It is important that, apart from the power transmitted through the circular aperture, all other power is absorbed within the mask material, so that unwanted power does not impinge on the radiation force balance target. The width of the aperture in the plane parallel to the **treatment head** should be greater than or equal to 4,5 cm. The aperture mask can be held with a holder appropriate for use with the particular radiation force balance, although it is important that no acoustically reflecting components are positioned within the ultrasonic field.

I.4 Measurement procedure for determining the effective radiating area

I.4.1 Power measurements made using the radiation force balance are carried out in the usual way, by switching the drive to the **treatment head** ON and OFF in a predefined manner (see IEC 61161).

I.4.2 For each of the individual aperture measurements, the output of the physiotherapy **treatment head** device under test shall be reset to a nominally identical power value, to ensure that it is operating under nominally identical conditions.

I.4.3 A power setting of 5 W is recommended for large **treatment heads** (effective diameter $> 2,0$ cm) as this represents a compromise between measurement sensitivity and restricting the extent of heating of any aperture mask material, which may be important.

NOTE The effective diameter is equal to twice the effective radius of the **treatment head** radius, a_1 . The effective radius may be derived from the manufacturer's value of the **effective radiating area**, using the expression: $a_1 = (A_{ER}/\pi)^{1/2}$. If the A_{ER} is not available, then the nominal **effective radiating area** (A_{ERN}) should be used to derive a value for a_1 .

I.4.4 For small **treatment heads** (effective diameters $< 1,5$ cm), the maximum power output should be used and this may typically lie in the range 0,9 W to 1,8 W. In addition, to restrict the irradiation time used, the switch ON time shall be limited to 5 s for each aperture to minimize any heating of the aperture surface.

I.4.5 In setting up, the **treatment head** shall be positioned as close to the aperture surface as possible but not touching – separations in the range 0,2 cm to 0,4 cm are acceptable. The surface of the **treatment head** and the front face of the aperture should be as parallel as possible.

I.4.6 It is important that the axis of symmetry of the reflecting target (if used) and the aperture axis are co-axial. The sensitivity of the results obtained using the aperture technique to alignment has been assessed [13], and it is sufficient to align the system by eye. The **treatment head** is then positioned centrally over the aperture, again purely by eye, such that the acoustic axis of the beam is assumed to be nominally coincident with that of the aperture and target. No re-positioning of the **treatment head** in the plane of the aperture is carried out for subsequent apertures.

NOTE 1 In order to aid alignment of the aperture below the surface of the **treatment head**, alignment cross-hairs can be marked on the surfaces of the aperture mask.

NOTE 2 Alignment of the target relative to the aperture may not be as critical for radiation force balances which employ an absorbing target.

NOTE 3 The co-axiality of the aperture and **treatment head** assumes that the spatial distribution of the intensity within the ultrasonic beam is broadly symmetrical and centred on the geometrical axis of the transducer. In

situations where crystal damage has occurred, this may not be the case and scanning the **treatment head** in the plane of a small diameter aperture (0,4 cm to 0,6 cm) will provide some guidance on how the power is distributed.

I.4.7 As in the case of power measurements, care should be taken to ensure there are no bubbles in the intervening path or on the surfaces of the aperture masks, these can normally be wiped clear using a paint-brush.

NOTE It may be found that small bubbles adhere to parts of the aperture. If these are generally positioned well away from the acoustic beam they should not influence the transmitted power. Pre-soaking of the apertures in water containing a small amount of detergent may also reduce this effect.

I.4.8 For each aperture, typically three or four switches OFF to ON and ON to OFF should be carried out and an average power taken in order to improve the statistics. Using the minimal irradiation time identified in I.4.4, this process should take around 30 s to 40 s in total.

I.4.9 In-between the aperture measurements, and certainly at the beginning and end of the run, a number of checks of the "free" or "unapertured" power should be made with no aperture in place.

I.4.10 A set of aperture measurements will typically comprise the results of around 12 apertures, along with three or four "unapertured" power measurements.

I.4.11 For small **treatment heads** whose effective diameter < 1,5 cm, these could typically cover aperture diameters in the range 0,4 cm to 1,8 cm.

I.4.12 For larger **treatment heads** whose effective diameter > 2,0 cm diameter, these could typically cover aperture diameters in the range 0,6 cm to 3,0 cm.

I.4.13 In either case, a reasonably even distribution of aperture sizes should be used.

NOTE With care in the experimental technique, values of power produced by a particular aperture should be reproducible to within $\pm 3\%$ to $\pm 4\%$.

I.4.14 In some situations, a "blank" aperture (essentially a layer of the mask material with no hole present, so it represents a continuous piece of absorber) might be useful. When this is placed in front of the **treatment head**, the power balance should read zero. If it does not, then there may be other signals affecting the balance reading (for example, radio-frequency electrical signals emitted by the transducer).

I.5 Analysis of raw data to derive the effective radiating area

I.5.1 General

This subclause provides a step-by-step breakdown of the data analysis procedure, taking a typical set of raw data. These have been derived from measurements made on a commercially available 1 MHz treatment head of effective diameter 2,2 cm, with the data having been acquired using nominal aperture diameters in the range 0,8 cm to 3,0 cm, using the method described in [11]. Table I.1 represents the raw data derived from a typical measurement run, showing transmitted power as a function of aperture diameter.

Table I.1 – Aperture measurement check sheet

Date: **/**/**

Operator: **

Treatment head: *****_*** **

Serial number: *****

Drive unit setting: 5,4 W

Frequency: 1 MHz

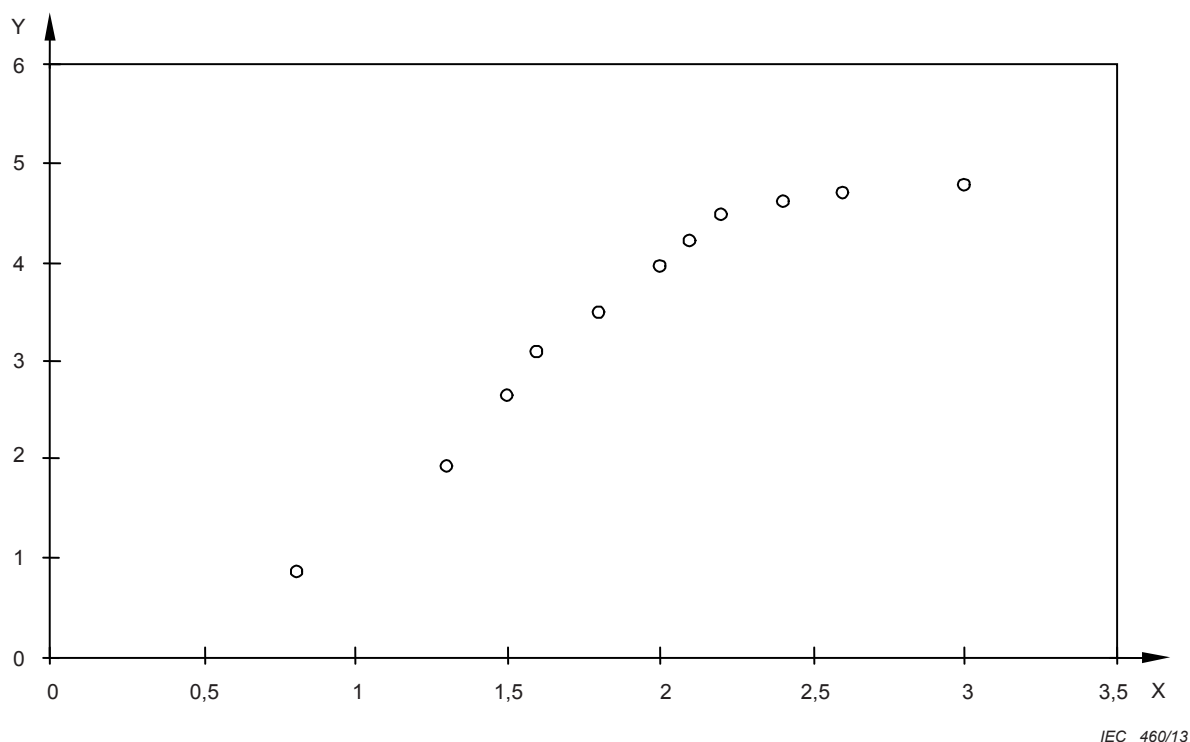
Aperture diameter cm	Radiation force balance readings (W)				
	OFF 1	ON 1	OFF 2	ON 2	Mean reading
No aperture	0,00	4,98	0,02	4,97	4,965
2,0	0,00	3,92	0,04	4,00	3,93
2,4	0,00	4,59	0,02	4,64	4,593
3,0	0,00	4,76	0,01	4,80	4,767
No aperture	0,00	4,88	0,01	4,90	4,88
2,6	0,00	4,70	0,03	4,74	4,693
2,0	0,00	3,96	0,02	3,92	3,933
2,1	0,00	4,26	0,01	4,34	4,28
2,2	0,00	4,52	0,02	4,49	4,497
1,6	0,00	3,07	0,00	3,12	3,087
No aperture	0,00	4,97	0,00	4,99	4,98
1,8	0,00	3,47	0,01	3,54	3,487
1,5	0,00	2,65	0,01	2,72	2,653
1,3	0,00	1,93	0,00	1,95	1,937
0,8	0,00	0,89	0,01	0,83	0,86
2,4	0,00	4,64	0,01	4,66	4,64
No aperture	0,00	4,87	0,01	4,94	4,887
2,0	0,00	4,00	0,01	4,02	4,00
1,8	0,00	3,49	0,00	3,52	3,5
2,1	0,00	4,16	0,00	4,17	4,163
2,2	0,00	4,55	0,01	4,58	4,553
1,6	0,00	3,13	0,02	3,10	3,107
2,6	0,00	4,75	0,01	4,72	4,733
3,0	0,00	4,86	0,00	4,80	4,84
No aperture	0,00	5,01	0,03	4,99	4,98

The data has been derived by switching the **treatment head** ON and OFF in the sequence indicated, the mean reading being calculated from:

$$[(ON1 - OFF1) + (ON1 - OFF2) + (ON2 - OFF2)]/3.$$

NOTE The data set has been derived using eleven apertures. Repeats have been carried out on several apertures to check on the reproducibility of the measurements. The "no aperture" power measurement has been repeated five times to improve statistics.

I.5.2 The data listed in Table I.1 is used to produce a graph, shown in Figure I.2. This demonstrates the expected variation in power as a function of aperture diameter.



Key
X aperture diameter (cm)
Y measured power (W)

Figure I.2 – Measured power as a function of aperture diameter for commercially-available 1 MHz physiotherapy treatment heads

To derive a value for **effective radiating area**, further data manipulation is required: the reason for this lies in the spatial distribution of **ultrasound** in the field produced by the physiotherapy **treatment head**, and in the fact that the **effective radiating area** is itself defined via a secondary parameter, the **beam cross sectional area** (A_{BCS}), which describes the minimum area through which the majority of the ultrasonic power is distributed. The raw data is actually analysed and "sorted" in a manner analogous to that described in Annex B. This procedure is described below in a step-by-step format.

I.5.3 From the raw data (power as function of aperture diameter), the nominal aperture diameters are converted to areas.

I.5.4 Considering the 0,8 cm diameter aperture, it transmits a power of 0,86 W (see Table I.1). By increasing the aperture size to 1,3 cm, the transmitted power is 1,94 W, and so the power difference of 1,08 W is assumed to be distributed evenly over an area equal to the annulus formed by the two apertures. By then taking the 1,5 cm aperture, and identifying its power contribution relative to the 1,3 cm aperture (0,72 W), a representation of the power distribution may be built up. This is done for all adjacent aperture pairs and the data obtained is illustrated in Table I.2.

NOTE For the 0,8 cm diameter aperture, the power is clearly distributed over a circle of radius 0,4 cm, and not an annulus.

Table I.2 – Annular power contributions

Aperture pair	Power contribution W
0 to 0,8	0,86
0,8 to 1,3	1,08
1,3 to 1,5	0,72
1,5 to 1,6	0,44
1,6 to 1,8	0,40
1,8 to 2,0	0,47
2,0 to 2,1	0,26
2,1 to 2,2	0,27
2,2 to 2,4	0,12
2,4 to 2,6	0,097
2,6 to 3,0	0,091

I.5.5 The power contributions from each annulus are converted into intensity contributions, by dividing the power contained in a particular annulus by the area of that annulus. This produces a data set of intensity contributions from each pair of successive apertures, and is shown in Table I.3.

Table I.3 – Annular intensity contributions

Aperture pair	Area of larger aperture cm ²	Annulus area cm ²	Power contribution W	Intensity contribution W cm ⁻²
0 to 0,8	0,503	0,503	0,86	1,71
0,8 to 1,3	1,327	0,825	1,08	1,31
1,3 to 1,5	1,767	0,440	0,72	1,64
1,5 to 1,6	2,011	0,243	0,44	1,81
1,6 to 1,8	2,545	0,534	0,40	0,75
1,8 to 2,0	3,142	0,597	0,47	0,79
2,0 to 2,1	3,464	0,322	0,26	0,81
2,1 to 2,2	3,801	0,338	0,27	0,80
2,2 to 2,4	4,524	0,723	0,12	0,17
2,4 to 2,6	5,309	0,785	0,097	0,12
2,6 to 3,0	7,069	1,759	0,091	0,05

I.5.6 The intensity contributions are then sorted in descending order, ensuring that the association is kept of the annulus area (aperture pair) that produced each contribution. This is shown in Table I.4.

Table I.4 – Annular intensity contributions, sorted in descending order

Aperture pair	Intensity contribution $W \times cm^{-2}$	Annulus area cm^2
1,5 to 1,6	1,81	0,243
0 to 0,8	1,71	0,503
1,3 to 1,5	1,64	0,44
0,8 to 1,3	1,31	0,825
2,0 to 2,1	0,81	0,322
2,1 to 2,2	0,8	0,338
1,8 to 2,0	0,79	0,597
1,6 to 1,8	0,75	0,534
2,2 to 2,4	0,17	0,723
2,4 to 2,6	0,12	0,785
2,6 to 3,0	0,05	1,759

NOTE From this data set, it is clear that most of the intensity lies centred about the acoustic beam axis between apertures 0 and 1,6 cm.

I.5.7 Each intensity value is converted back to a power value by multiplying by the corresponding annular area. This produces a data set of power contributions and annular areas, which have actually been sorted in order of descending intensity. This is shown in Table I.5.

Table I.5 – Annular power contributions, sorted in descending order of intensity contribution

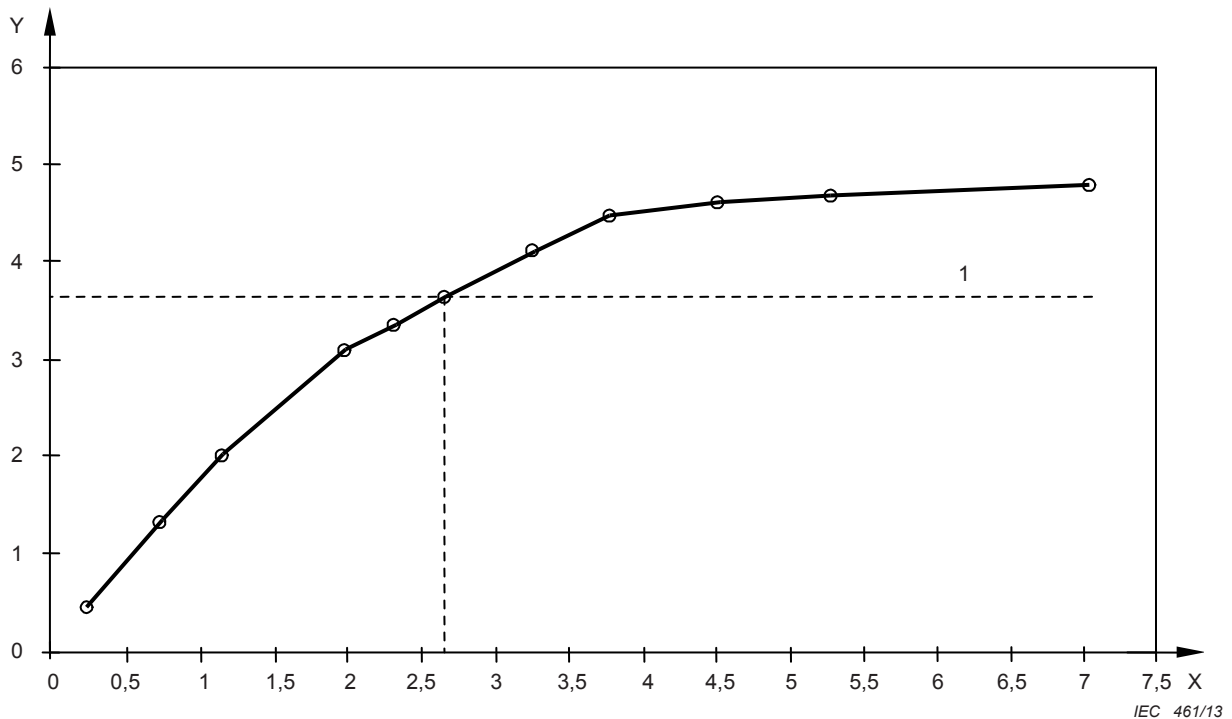
Aperture pair	Intensity contribution $W \text{ cm}^{-2}$	Annulus area cm^2	Power contribution W
1,5 to 1,6	1,81	0,243	0,44
0 to 0,8	1,71	0,503	0,86
1,3 to 1,5	1,64	0,44	0,72
0,8 to 1,3	1,31	0,825	1,08
2,0 to 2,1	0,81	0,322	0,26
2,1 to 2,2	0,8	0,338	0,27
1,8 to 2,0	0,79	0,597	0,47
1,6 to 1,8	0,75	0,534	0,40
2,2 to 2,4	0,17	0,723	0,12
2,4 to 2,6	0,12	0,785	0,09
2,6 to 3,0	0,05	1,759	0,09

I.5.8 A running sum is then produced of cumulative power against cumulative area, by summing the values down the table (the cumulative power total should be equal to the power transmitted through the largest aperture). This is shown in Table I.6.

Table I.6 – Cumulative sum of annular power contributions, previously sorted in descending order of intensity contribution, and the cumulative sum of their respective annular areas

Intensity contribution W cm ⁻²	Annulus area cm ²	Power contribution W	Cumulative area cm ²	Cumulative power W
1,81	0,243	0,44	0,24	0,44
1,71	0,503	0,86	0,75	1,30
1,64	0,44	0,72	1,19	2,02
1,31	0,825	1,08	2,01	3,10
0,81	0,322	0,26	2,33	3,36
0,8	0,338	0,27	2,67	3,63
0,79	0,597	0,47	3,27	4,11
0,75	0,534	0,40	3,80	4,51
0,17	0,723	0,12	4,53	4,63
0,12	0,785	0,09	5,31	4,72
0,05	1,759	0,09	7,07	4,81

I.5.9 A figure should then be plotted, of cumulative power as a function of cumulative area, as in Figure I.3. From the value of power measured for the "unapertured" case (4,89 W), calculate the 75 % transmitted power (3,67 W), and read off the cumulative area at this power level. The cumulative area value is finally divided by 0,75 to derive an estimate of the **effective radiating area of the treatment head**.



Key

- X cumulative area (cm²)
- Y cumulative power (W)
- 1 represents 75 % level of power

Figure I.3 – Cumulative sum of annular power contributions, previously sorted in descending order of intensity contribution, plotted against the cumulative sum of their respective annular areas

NOTE The **treatment head** analysed in this case has an **effective radiating area** of 3,5 cm², given by the quotient of 2,65 cm² to 0,75.

I.6 Implementation of the aperture technique

It is envisaged that the aperture method will be applied in a number of different ways, for example:

- as a means of acceptance testing prior of a **treatment head** being placed into clinical service, a full characterization could be carried out using many apertures (> 12). This would then produce a reference curve for that **treatment head**;
- as a means of routine evaluation, on an annual basis, using only two or three apertures to compare with the reference curve;
- as a means of verifying continual reliable performance, if a **treatment head** has been dropped or damaged: again, this could be done using a limited number of apertures, followed by more extensive tests if differences are noted.

I.7 Relationship of results to reference testing method

Bibliographic reference [11] represents a comparison of the aperture method with **hydrophone** measurements carried out using the test procedures given in Clause 7 for seventeen **treatment heads** commonly used in clinical practice. Although differences for some **treatment heads** were noticed of up to $\pm 20\%$, the typical level of agreement was $\pm 11\%$. A recent report [13] contains details of measurements made using the apertures with implementations of a radiation force balance which utilizes absorbing and reflecting targets.

NOTE In general, the aperture technique gives best agreement (typically $\pm 11\%$) with results for the A_{ER} determined through **hydrophone** scanning for large ka transducers ($ka > 50$). For transducers with $ka < 30$, the agreement with the reference technique is typically $\pm 20\%$.

Annex J (informative)

Guidance on uncertainty determination

To be truly meaningful, the result of a measurement must be accompanied by its associated uncertainty. In evaluating and expressing the uncertainty in the measurement, the guidance provided by [14] should be followed.

In general, uncertainty components are grouped according to how the values are estimated:

- Type A: evaluated by statistical means;
- Type B: evaluated by other means.

The following is a list of common sources of uncertainty in the measurement of **ultrasonic physiotherapy equipment** that may be evaluated on a Type B basis. The list is not exhaustive, but may be used as a guide when assessing uncertainties for a particular measurement system or method. Depending on the parameter under consideration, the measurement system and method chosen and its implementation, some (though possibly not all) of these sources will need assessing. For example, the errors from measuring instruments may be minimized by the use of the same measuring channel (amplifier, filter, voltmeter, etc.) for all signals. However, since this may not be the case in all implementations, components for these sources of error have been included in the list.

Sources of uncertainty applicable to **hydrophone** measurements in general:

- interference from acoustic reflections, leading to a lack of free-field conditions;
- lack of acoustic far-field conditions;
- spatial averaging effects of the **hydrophones** used due to their finite size and the lack of perfect plane-wave conditions;
- misalignment, particularly at higher frequencies where the **hydrophone** response may be far from omnidirectional;
- acoustic scattering from the **hydrophone** mount (or vibrations picked up and conducted by the mount);
- errors in measurement of the received voltage (including the accuracy of the measuring instrumentation – voltmeter, digitizers, etc.);
- inaccuracy of the gains of any amplifiers, filters and digitizers used;
- errors in the measurement of the drive current or voltage;
- errors due to the lack of linearity in the measurement system (the use of a calibrated attenuator to equalize the measured signals may significantly reduce this contribution);
- inaccuracy of any electrical signal attenuators used;
- electrical noise including RF pick-up;
- inaccuracy of any electrical loading corrections made to account for loading by extension cables and preamplifiers;
- bubbles or air clinging to transducers (this should be minimized by adequate wetting and soaking of transducers);
- errors in the values for acoustic frequency.

Sources of uncertainty specific to determination of **effective radiating area** and **total mean square acoustic pressure**:

- errors in the measurement of the separation distance;

- spatial resolution of the beam scans carried out (local structure which may be undersampled).

More details about uncertainty calculation of **effective radiating area**, **total mean square acoustic pressure** and **beam non-uniformity ratio** can be found in [15] and [16].

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Related IEC documents

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <<http://www.electropedia.org>>)

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

IEC 60050-802:2011, *International Electrotechnical Vocabulary – Part 802: Ultrasonics*

IEC 60469-1, *Pulse techniques and apparatus – Part 1: Pulse terms and definitions*

IEC/TR 60854, *Methods of measuring the performance of ultrasonic pulse-echo diagnostic equipment*

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

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

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

IEC/TS 62781, *Ultrasonics – Conditioning of water for ultrasonic measurements*



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