

BS EN 62555:2014



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Ultrasonics — Power measurement — High intensity therapeutic ultrasound (HITU) transducers and systems

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National foreword

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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 -
Power measurement -
High intensity therapeutic ultrasound (HITU) transducers and systems
(IEC 62555:2013)**

Ultrasons -
Mesurage de puissance -
Transducteurs et systèmes ultrasonores
thérapeutiques de haute intensité (HITU)
(CEI 62555:2013)

Ultraschall -
Leistungsmessung -
Messung der Ausgangsleistung für
hochintensive, therapeutische
Ultraschallwandler und -systeme
(IEC 62555:2013)

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Foreword

The text of document 87/538/FDIS, future edition 1 of IEC 62555, prepared by IEC TC 87 "Ultrasonics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62555:2014.

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) 2014-10-25
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2016-12-24

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

IEC 62127-2	NOTE	Harmonized as EN 62127-2
IEC 60601-2-62	NOTE	Harmonized as EN 60601-2-62

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 61161	2013	Ultrasonics - Power measurement - Radiation force balances and performance requirements	EN 61161	2013
IEC/TR 62781		Ultrasonics - Conditioning of water for ultrasonic measurements	-	-

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INTRODUCTION

In ultrasound fields at megahertz frequencies, output power is typically determined by measuring the force on a target using a radiation force balance [1],[2],[3]. However, the relationship between the radiation force and the output power is affected by the focusing or other geometrical aspects of the field, by the type and shape of the target, by the distance of the target from the transducer, by absorption (including 'shock-loss') in the water path, and by acoustic streaming currents. Whilst many of these effects are small for typical diagnostic or physiotherapy ultrasound fields, they cannot generally be ignored for HITU fields (particularly for those often referred to as high intensity focused ultrasound HIFU) [4]. Furthermore, in HITU, the quantity of interest is the power incident on the patient rather than the output power at the transducer face. Since it is common to have a water stand-off between the transducer and the patient, attenuation and shock-loss in the water path may be significant and will vary depending upon the chosen distance.

The purpose of this International Standard is to establish standard methods of measurement of ultrasonic power of HITU devices in liquids in the lower megahertz frequency range based on the measurement of the radiation force using a gravimetric balance, and calorimetry (based on the measurement of thermal expansion). This standard identifies the sources of errors and describes a systematic step-by-step procedure to assess overall measurement uncertainty as well as the precautions that should be undertaken and uncertainties that should be taken into account while performing power measurements. Practical guidance is given for the determination of acoustic power from the very wide range of transducer geometries used for HITU. Unlike radiation force approaches in IEC 61161 that deal with "time average power," other power measurement methods are described in this document.

The structure and content of parts of this International Standard are largely based on IEC 61161:2013 but there are differences that are summarised below. In this standard the prime measurand is considered to be the incident power, and not the output power. Output power is always the quantity of interest in IEC 61161, which specifies that measurements are made with the target placed close to the transducer. However, this may not always be possible for strongly convergent transducers and there are cases where it is more relevant to measure the incident power which reaches a specified surface at some substantial distance from the transducer (this surface may represent the skin surface of the patient, for instance). This extra distance may result in significant nonlinear loss in the water path even at low megahertz frequencies. Consequently, in this International Standard the prime measurand is considered to be the incident power, and not the output power. The incident power may of course be the basis for determining the output power using an appropriate model with its own uncertainties.

ULTRASONICS – POWER MEASUREMENT – HIGH INTENSITY THERAPEUTIC ULTRASOUND (HITU) TRANSDUCERS AND SYSTEMS

1 Scope

This International Standard

- establishes general principles relevant to **HITU** fields for the use of **radiation force** balances in which an obstacle (**target**) intercepts the sound field to be measured;
- specifies a calorimetric method of determining the total emitted acoustic power of **ultrasonic transducers** based on the measurement of thermal expansion of a fluid-filled target;
- specifies requirements related to the statement of electrical power characteristics of **ultrasonic transducers**;
- provides guidance related to the avoidance of acoustic cavitation during measurement;
- provides guidance related to the measurement of HITU transducers of different construction and geometry, including collimated, diverging and convergent transducers, and multi-element transducers;
- provides guidance on the choice of the most appropriate measurement method;
- provides information on assessment of overall measurement uncertainties.

This International Standard is applicable to the measurement of ultrasonic power generated by **HITU equipment** up to 500 W in the frequency range from 0,5 MHz to 5 MHz. **HITU equipment** may generate convergent, collimated or divergent fields.

For frequencies less than 500 kHz, no validations exist and the user should assess the uncertainties of the power measurement and measurement system at the frequencies of operation.

This International Standard does not apply to:

- ultrasound equipment used for physiotherapy, for lithotripsy for general pain relief.

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 61161:2013, *Ultrasonics – Power measurement – Radiation force balances and performance requirements*

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

3 Terms and definitions

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

3.1**acoustical efficiency** η_a

ratio of the acoustic **output power** from an **ultrasonic transducer** to the **transducer electrical power**

Note 1 to entry: **Acoustical efficiency** is unitless.

3.2**acoustic streaming**

bulk fluid motion initiated by a sound field

[SOURCE: IEC 61161:2013, 3.1]

3.3**buoyancy sensitivity** S

ratio of the increase in the buoyancy force on an **expansion target** to the amount of absorbed energy in the absence of thermal losses

Note 1 to entry: This ratio may be temperature dependent.

Note 2 to entry: The **buoyancy sensitivity** for a fluid filled expansion target immersed in water is most conveniently and most accurately determined by calibration using electrical heating (see 7.2.9). It can also be calculated from the product of the **expansion ratio**, the density of the water and the acceleration due to gravity but, in practice, this leads to higher uncertainties.

Note 3 to entry: Since most sensitive balances display weight in grams or milligrams, the **buoyancy sensitivity** is often more conveniently expressed as mass-equivalent **buoyancy sensitivity** in terms of a mass-equivalent unit, such as mg J^{-1} .

Note 4 to entry: **Buoyancy sensitivity** is expressed in Newton per Joule, N J^{-1} .

3.4**expansion ratio** R_V

ratio of the increase in volume of the liquid inside an **expansion target** to the amount of absorbed energy in the absence of thermal losses

Note 1 to entry: Subject to certain assumptions, the **expansion sensitivity** for a fluid-filled **expansion target** can be calculated from the ratio of the volume expansivity of the fluid to its volumetric heat capacity. The ratio may be temperature dependent.

Note 2 to entry: **Expansion ratio** is expressed in cubic metre per Joule, $\text{m}^3 \text{J}^{-1}$.

3.5**expansion target**

a liquid-filled device specially designed to intercept and absorb substantially all of the ultrasonic field and to undergo thermal expansion

3.6**free field**

sound field in a homogeneous isotropic medium whose boundaries exert a negligible effect on the sound waves

[SOURCE: IEC 60050-801:1994, 801-23-28, modified – the term no longer contains “sound”]

3.7**high intensity therapeutic ultrasound (HITU) equipment**

equipment for the generation and application of ultrasound to a patient for therapeutic purposes with the intention to destroy, disrupt or denature living tissues or non-tissue elements (for example, liquids, bubbles or micro-capsules) and which aims notably at making

treatments through actions of ultrasound having mechanical, thermal or more generally physical, chemical or biochemical effects

Note 1 to entry: Essentially **HITU equipment** comprises a generator of electric high-frequency power and a transducer for converting this to ultrasound. In a lot of cases this equipment also includes a targeting and monitoring device.

Note 2 to entry: HITU may as a side effect by its operation induce hyperthermia, however it should not be confused with this technique, which heats much less rapidly and to much lower therapeutic temperatures (in general 42 °C to 50 °C and thermal equivalent times of 0,2 min to 120 min). **HITU equipment** typically causes temperature rises in excess of 55 °C and for much shorter times: alternatively, HITU may also induce bioeffects by non-thermal mechanisms.

Note 3 to entry: This definition does not apply to: ultrasound equipment used for physiotherapy, ultrasound equipment used for lithotripsy or ultrasound equipment used for general pain relief.

[SOURCE: IEC 60601-2-62:2013, 201.3.218, modified – the Note 3 to entry refers to "general pain relief" instead of "dedicated hyperthermia".]

3.8

incident power

P_i

time-average ultrasonic power reaching a specified plane or surface after being emitted by an **ultrasonic transducer** into an approximately **free field**, under specified conditions and in a specified medium, preferably water

Note 1 to entry: **Incident power** is expressed in watt, W

3.9

multi-element transducer

a source of ultrasound comprising two or more spatially separated **ultrasonic transducers**

Note 1 to entry: In this context, a single piezoelectric element in a phased array is considered to be an **ultrasonic transducer**.

3.10

nonlinear loss

loss of energy from an ultrasound beam due to the absorption of harmonic components which arise from nonlinear propagation effects

Note 1 to entry: In general, **nonlinear loss** does not occur uniformly throughout an ultrasound field but occurs preferentially where the pressure amplitude is greatest, resulting in a change in the relative distribution of ultrasound energy.

3.11

output power

P

time-average ultrasonic power emitted by an **ultrasonic transducer** into an approximately **free field** under specified conditions in a specified medium, preferably water

Note 1 to entry: **Output power** is expressed in watt, W

[SOURCE: IEC 61161:2013, 3.3]

3.12

radiation conductance

G

ratio of the acoustic **output power** and the squared r.m.s. transducer input voltage.

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

Note 2 to entry: The r.m.s. drive voltage is used (rather than, for instance, peak-to-peak drive voltage) because its value is less affected by distortion of the applied electrical signal.

Note 3 to entry: This term is not the same as the real part of transducer admittance.

Note 4 to entry: **Radiation conductance** is expressed in siemens, S

[SOURCE: IEC 61161:2013, 3.8, modified –two notes to entry relevant to HITU have been added]

3.13

radiation force

acoustic radiation force

F

time-average force acting on a body in a sound field and caused by the sound field, excluding the component due to **acoustic streaming**

Note 1 to entry: More generally: time-average force (excluding the component due to **acoustic streaming**) in a sound field, appearing at the boundary surface between two media of different acoustic properties

Note 2 to entry: **Radiation force** is expressed in Newton, N

[SOURCE; IEC 61161:2013, 3.4 modified – the second part of the original definition is presented as a note to entry, but without the phrase "or within a single attenuating medium"]

3.14

radiation force target

device specially designed to intercept substantially all of the ultrasonic field and to serve as the object which is acted upon by the **radiation force**

3.15

target

device specially designed to intercept substantially all of the ultrasonic field

3.16

transducer electrical power

P_{el}

rate at which time-average electrical energy is converted by an **ultrasonic transducer** into other forms of energy (typically into heat and the energy of the ultrasonic field)

Note 1 to entry: Electrical power which is reflected from the **ultrasonic transducer** is not part of the **transducer electrical power**.

Note 2 to entry: **Transducer electrical power** is expressed in Watt, W

3.17

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

Note 1 to entry: An **ultrasonic transducer** may include connected cables and components for electrical matching.

4 List of symbols

a	radius of a circular ultrasonic source transducer
b_x and b_y	half-dimensions of a rectangular ultrasonic transducer in x and y direction, respectively (so that $2b_x$ and $2b_y$ are the transducer's side lengths)
B	change in the buoyancy force acting on an expansion target immersed in a sound propagating medium (usually water)
c	speed of sound (usually in water)
d_x and d_y	geometrical focal lengths of a convergent ultrasonic transducer in the x - z and the y - z plane, respectively

d	geometrical focal length of a convergent ultrasonic transducer , in the case that $d_x = d_y = d$
C	the volumetric heat capacity
E	the volumetric expansion coefficient
F	radiation force on a target in the direction of the incident ultrasonic wave
g	acceleration due to gravity
G	radiation conductance
h_d	half the diagonal of a rectangular transducer, $h_d = (b_x^2 + b_y^2)^{1/2}$
h_h	harmonic mean of b_x and b_y , $h_h = 2 / (1/b_x + 1/b_y)$
k	circular wavenumber ($2\pi/\lambda$)
L	the fraction of acoustic streaming momentum recovered by a target
M	the time-varying weight of a target or expansion target as it is displayed by the supporting balance (often in mass-equivalent units)
P	output power of an ultrasonic transducer
P_{el}	the transducer electrical power
P_i	incident power on a target or expansion target
R_c	radius of curvature of a focused bowl transducer
R_V	the expansion ratio of an expansion target
s	normalized distance from an ultrasonic transducer ($s = z \lambda / a^2$)
S	the buoyancy sensitivity of an expansion target
t_0	the duration of insonation
z	distance between a target and the radiating surface of an ultrasonic transducer measured along the beam-axis
α	amplitude attenuation coefficient of plane waves in a medium (usually water)
β_x and β_y	focus (half-)angles of a convergent ultrasonic transducer in the x - z and the y - z plane, respectively; $\beta_x = \arctan(b_x/d_x)$, $\beta_y = \arctan(b_y/d_y)$ if the transducer is planar and the focal lengths are counted from the planar transducer surface
γ	focus (half-)angle of a circular convergent ultrasonic transducer ; $\gamma = \arcsin(a/d)$ if the transducer is spherically curved and the focal length is counted from the "bottom" of the "bowl"; $\gamma = \arctan(a/d)$ if the focal length is counted from the plane defined by the rim of the active part of the "bowl" or if the transducer is planar
η_a	the acoustic efficiency of an ultrasonic transducer
θ	angle between the direction of the incident ultrasonic wave and the normal to the surface of a target
ϕ	angle between the direction of the incident ultrasonic wave and the sensitive axis (usually vertical) of a balance
λ	ultrasonic wavelength in the sound-propagating medium (usually water)
ρ	(mass) density of the sound-propagating medium (usually water).

NOTE The direction of the incident wave mentioned above under F and θ is understood to be the direction of the field axis, i.e., it is understood in a global sense rather than in a local sense.

5 Power measurement for HITU equipment

Measurement of **output power** is well established for collimated (and weakly convergent or weakly divergent) ultrasound fields at powers up to 20 W using the **radiation force** method [IEC 61161]. Clause 6 of this International Standard is based on IEC 61161:2011.

changes are introduced to make it more appropriate for **HITU equipment** which in general is not collimated and has higher **output power**. IEC 61161 specifies that measurements are made with the **target** placed close to the transducer. However, this may not always be possible for strongly convergent transducers and there are cases where it is more relevant to measure the **incident power** which reaches a specified surface at some substantial distance from the transducer (this surface may represent the skin surface of the patient, for instance). This extra distance may result in significant **nonlinear loss** in the water path. Consequently, in this International Standard the prime measurand is considered to be the **incident power**, and not the **output power**. The **incident power** may of course be the basis for determining the **output power** using an appropriate model with its own uncertainties (guidance is given in Annex E). Although the buoyancy change method determines the time-average power incident on the **target** during the insonation time, the **radiation force** method actually determines the turn-on and turn-off power. These two values may be different to each other, and the average of the two is not necessarily equal to the time-average power. In general, insonation time is adjusted as appropriate to the measuring device to account for device limitations.

6 Radiation force on a target

6.1 General

The **radiation force** balance shall consist of a **target** which is connected to a balance. The ultrasonic beam shall be directed vertically upwards or downwards or horizontally on the **target** and the **radiation force** exerted by the ultrasonic beam shall be measured by the balance. The incident ultrasonic power shall be determined from the difference between the force measured with and without ultrasonic radiation. Calibration of the balance can be carried out by means of small precision weights of known mass.

The **target** shall be chosen so as to closely approach one of the two extreme cases, i.e. perfect absorber or perfect reflector.

For a plane incident wave only, the acoustic **incident power** P_i from the **ultrasonic transducer** shall be calculated from the **radiation force** component F on the **target** in the propagation direction using Equation 1 or 2 as appropriate:

For a perfectly absorbing **target**:

$$P_i = cF \quad (1)$$

For a perfectly reflecting **target**:

$$P_i = cF / (2 \cos^2 \theta) \quad (2)$$

where

c is the speed of sound in the sound-propagating fluid (water);

θ is the angle between the propagation direction of the incident wave and the normal to the reflecting surface

NOTE 1 The direction of the incident wave mentioned above is understood to be the direction of the field axis, i.e., it is understood in a global sense rather than in a local sense.

The relationship between **radiation force** and **incident power** depends in principle on assumptions about the radiated field and its interaction with the **target** and the measurement tank. For any non-plane wave (e.g. convergent, divergent or arising from multiple simultaneous sources), the correct relationship between **radiation force** and **incident power** shall be determined. The uncertainty in the **incident power** due to the non-plane nature of the field shall be estimated.

In some cases, forces on the **target** due to **acoustic streaming** may be significant compared to the **radiation force**. In order to determine the magnitude of the **radiation force** in these cases, corrective measures shall be taken which may include applying a theoretical correction or the use of a streaming foil close to the **target**. Guidance is given in Annex E. The uncertainty in the **incident power** due to streaming forces shall be estimated.

NOTE 2 The appropriate formulae for certain simple idealised transducer configurations are given in Annex C.

The **incident power** should be measured with the transducer driven in a way similar to its intended clinical use (e.g. continuous wave or with the usual clinical pulsing sequence, provided this is compatible with the time response of the balance).

If it is necessary to use a different pulsing sequence to avoid damage to the **target** or to the transducer, the effect of different thermal loading on the power output of the transducer shall be investigated

Further background information about the requirements in the remainder of Clause 6 can be found in Annex A of IEC 61161:2013.

6.2 Requirements for equipment

6.2.1 Target type

6.2.1.1 General

The use of an absorbing **target** is recommended. The use of a conical reflecting **target** is not recommended in general but may be necessary in some situations.

The **target** shall have known acoustic properties, these being relevant to the details of the relation between ultrasonic power and **radiation force**. (See also A.5.2 of IEC 61161:2013)

6.2.1.2 Absorbing target

An absorbing **target** shall have:

- an amplitude reflection factor of less than 5 %;
- an acoustic energy absorption within the **target** of at least 98 %.

For measurements on a collimated transducer, an absorbing **target** should be orientated at a small angle to the axis of symmetry of the transducer to minimise coherent reflections.

The absorbing material and the design of the **target** shall be chosen to reduce the risk of permanent thermal and mechanical damage by the ultrasound exposure. Temporary changes in the amplitude reflection factor or acoustic energy absorption shall be such that the impact on the overall measured power is less than 2 %, otherwise a correction shall be applied.

6.2.1.3 Reflecting target

A reflecting **target** shall have an amplitude reflection factor greater than 99 %.

The possibility of some part of the ultrasound energy being reflected back to the transducer from the **target** shall be considered and the shape of the **target** shall be chosen appropriately for the transducer geometry.

A conical reflecting **target** is not generally suitable for measurements in convergent or divergent fields and a conical reflecting **target** should not be used to measure convergent transducers, **multi-element transducers** or transducers where $ka < 17,4$ unless specific factors such as transducer geometry make it essential. If use of a conical reflecting **target** is essential due to the shape of the transducer, then the expected relationship between

power and **radiation force** shall be estimated. Uncertainty due to this relationship shall be included in 6.4.2.

NOTE 1 The exact meaning of the quantity *a* depends on circumstances. For practical transducers, this is the effective transducer radius in accordance with the particular definition in the field of application. In model calculations using a piston approach, it is the geometrical piston radius.

6.2.2 Target diameter

The **target** diameter shall be large enough to intercept at least 98 % of the ultrasound energy reaching the measurement plane. Formulae for estimating the required **target** diameter are given in Annex B.

NOTE Other methods may be used to determine the minimum **target** diameter for an individual transducer design: for instance, modelling or hydrophone measurements.

6.2.3 Balance / force measuring system

The **radiation force** balance may be a gravimetric balance with, therefore, the beam orientation vertical. Alternatively the balance may be of a force feed-back design, allowing the beam to be horizontal. If the balance has been calibrated against mass units, a correct conversion of the balance readings to force values shall be ensured by the manufacturer of the **radiation force** device or by the user.

NOTE Calibration of set-ups with horizontal beam orientation may be carried out using an appropriate balance arm attachment, or by calibration against sources of known acoustic power.

The balance used shall have sufficient resolution for the magnitude of the ultrasonic power to be measured. (See A.5.4 of IEC 61161:2013)

6.2.4 System tank

If a reflecting **target** is used, an absorbing lining of the measuring vessel shall be used so that returning reflections do not contribute to more than 2 % of the overall measured power.

6.2.5 Target support structures

In static-force balances, the structural members supporting the **target** and carrying the **radiation force** across the air-water interface shall be designed to limit the effect of surface tension and buoyancy changes caused by water level fluctuations to less than 2 % of the overall measured power.

6.2.6 Transducer positioning

The **ultrasonic transducer** mount shall allow stable and reproducible positioning of the **ultrasonic transducer** with respect to the **target** in a way that related changes in overall measured power do not exceed 2 %.

6.2.7 Anti-streaming foils

The **target** shall be either provided with an anti-streaming foil to isolate it from **acoustic streaming** in the water path or the measurement process, including data acquisition and analysis, shall be performed in such a way that streaming forces cause no more than a 2 % effect on the overall measured power, otherwise a correction shall be applied.

If an anti-streaming foil is used it shall be positioned close to the **target** and shall not be oriented parallel to the surface of the **ultrasonic transducer**. Its transmission coefficient shall be known from measurement and a correction shall be applied if its influence is more than 2 % of the overall measured power.

NOTE In practice a tilt angle of 5° to 10° has been found to be adequate.

6.2.8 Transducer coupling

The **ultrasonic** transducer shall be coupled to the measurement device such that the impact on the overall measured power is less than 2 %, otherwise a correction shall be applied. (See also A.5.9 of IEC 61161:2013)

6.2.9 Calibration and stability

The force measuring part of the **radiation force** balance shall be calibrated by the use of small weights of known mass.

Changes in the sensitivity of the **radiation force** balance to ultrasonic power shall be monitored by use of an ultrasonic source of known **output power**. The sensitivity shall be tested every year or more frequently if there is any indication that the balance sensitivity to ultrasonic power has changed.

NOTE The sensitivity to ultrasonic power may change due to degradation of the **target** material caused, for instance, by thermal or cavitation damage.

6.3 Requirements for measuring conditions

6.3.1 Lateral target position

The lateral position of the **target** during measurement shall be constant and reproducible to an extent that related changes in overall measured power do not exceed 2 %.

6.3.2 Transducer/target separation

The distance between the **ultrasonic transducer** surface and the **target**, or foil (if used) and **target**, shall be known and reproducible to an extent that possible changes in overall measured power do not exceed 2 %.

6.3.3 Water

When using a **radiation force** balance, the liquid used for the measurements shall be water.

For determining **output powers** above 1 W, only degassed water shall be used. Degassing of water shall be accomplished in a well-defined process such as described in IEC 62781. The water shall be degassed sufficiently to avoid the formation of visible bubbles in the water path or on the surfaces of the transducer or **target**. Measurements shall be discarded if any air bubbles are observed. The total amount of dissolved gas in the water should preferably be < 2 mg/l during all measurements, and may need to be lower in some cases.

The use of degassed water is also recommended for determining **output powers** below 1 W. Bubbles may form on surfaces in gassy water if the temperature of the water increases. Bubbles formation can also be induced by ultrasound and may also form at power levels below 1 W if the beam-area is small enough. Consequently it is recommended to check for the presence of bubbles especially on the transducer and **target** surfaces before, during and after each measurement.

NOTE 1 The gas level required to prevent bubble formation will depend on many factors including acoustic working frequency and maximum negative pressure in the water path. Changing or fluctuating **radiation force** may indicate the formation of bubbles.

NOTE 2 Chemical degassing methods which remove only one or a few gas components (eg the use of Na_2SO_3) are not generally sufficient for HITU measurements. Provided more general methods of degassing are used, monitoring of the oxygen content is simple to do and provides information about the effectiveness of the degassing and the extent of subsequent regassing.

NOTE 3 Filtration of the water can be helpful to avoid or reduce cavitation by removing particulate matter which can act as cavitation nuclei.