

Ultrasonics — Power measurement — Radiation force balances and performance requirements

The European Standard EN 61161:2007 has the status of a
British Standard

ICS 17.140.50

National foreword

This British Standard was published by BSI. It is the UK implementation of EN 61161:2007. It is identical with IEC 61161:2006. It supersedes BS EN 61161:1995 which is withdrawn.

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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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 October 2007

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ISBN 978 0 580 50695 6

Amendments issued since publication

Amd. No.	Date	Comments

English version

**Ultrasonics -
Power measurement -
Radiation force balances and performance requirements
(IEC 61161:2006)**

Ultrasons -
Mesurage de puissance -
Balances de forces de rayonnement
et exigences de fonctionnement
(CEI 61161:2006)

Ultraschall -
Leistungsmessung -
Schallfeldkraft-Waagen
und Anforderungen an ihre
Funktionseigenschaften
(IEC 61161:2006)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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Ref. No. EN 61161:2007 E

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Foreword

The text of document 87/325/CDV, future edition 2 of IEC 61161, prepared by IEC TC 87, Ultrasonics, was submitted to the IEC-CENELEC parallel Unique Acceptance Procedure and was approved by CENELEC as EN 61161 on 2007-03-01.

This European Standard supersedes EN 61161:1994 + A1:1998.

The main significant changes are:

- the main body of the standard has been restricted to normative statements;
- informative statements on corresponding aspects of ultrasonic power measurement and radiation force balances have been collected in Annex A;
- Annexes A, D, E and F are new;
- more radiation force balance arrangements are dealt with. The new material relates particularly to power measurement of ultrasonic physiotherapy devices.

The following dates were fixed:

- | | | |
|--|-------|------------|
| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2007-12-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2010-03-01 |

The following print types are used:

- requirements: roman type;
- notes: small roman type;
- words in **bold** in the text are defined in Clause 3.

The numbers in square brackets refer to the Bibliography (after the annexes).

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61161:2006 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

A number of measuring methods exist for the determination of the total emitted power of ultrasonic transducers ([1], [2], [3], see also Annex C). The purpose of this International Standard is to establish standard methods of measurement of ultrasonic power in liquids in the lower megahertz frequency range based on the measurement of the radiation force using a gravimetric balance. The great advantage of radiation force measurements is that a value for the total radiated power is obtained without the need to integrate field data over the cross-section of the radiated sound beam. 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

Basic safety requirements for ultrasonic physiotherapy devices are identified in IEC 60601-2-5 and make reference to IEC 61689, which specifies the need for acoustic power measurements with an uncertainty better than $\pm 15\%$. Considering the usual degradation of accuracy in the practical application of this standard, reference measurement methods need to be established with uncertainties better than $\pm 7\%$. Ultrasonic diagnostic device declaration requirements, including acoustic power, are specified in other IEC standards, as for example in IEC 61157.

The measurement of acoustic power accurately, precisely and repeatably using a radiation force balance as defined in this standard is influenced by a number of practical problems. As a guide to the user, additional information is provided in Annex A using the same section and clause numbering as the main body.

ULTRASONICS – POWER MEASUREMENT – RADIATION FORCE BALANCES AND PERFORMANCE REQUIREMENTS

1 Scope

This International Standard

- specifies a method of determining the total emitted acoustic power of ultrasonic transducers based on the use of a radiation force balance;
- establishes general principles for the use of radiation force balances in which an obstacle (target) intercepts the sound field to be measured;
- establishes limitations of the radiation force method related to cavitation and temperature rise;
- establishes quantitative limitations of the radiation force method in relation to diverging and focused beams;
- provides information on assessment of overall measurement uncertainties.

This International Standard is applicable to:

- the measurement of ultrasonic power up to 1 W based on the use of a radiation force balance in the frequency range from 0,5 MHz to 25 MHz;
- the measurement of ultrasonic power up to 20 W based on the use of a radiation force balance in the frequency range 0,75 MHz to 5 MHz;
- the measurement of total ultrasonic power of transducers, preferably with well-collimated beams;
- the use of radiation force balances of the gravimetric type or force feedback type.

NOTE The titles of all publications referred to in this Standard are listed in the Bibliography.

2 Normative references

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

IEC 60050, *International Electrotechnical Vocabulary (IEV) – Chapter 801: Acoustics and Electroacoustics, Chapter 802: Ultrasonics*

IEC 60854:1986, *Methods of measuring the performance of ultrasonic pulse-echo diagnostic equipment*

IEC 60866:1987, *Characteristics and calibration of hydrophones for operation in the frequency range 0,5 MHz to 15 MHz*

IEC 61101:1991, *The absolute calibration of hydrophones using the planar scanning technique in the frequency range 0,5 MHz to 15 MHz*

IEC 61102:1991, *Measurement and characterisation of ultrasonic fields using hydrophones in the frequency range 0,5 MHz to 15 MHz*

IEC 61689:1996, *Ultrasonics – Physiotherapy systems – Performance requirements and methods of measurement in the frequency range 0,5 MHz to 5 MHz*

IEC 61846:1998, *Ultrasonics – Pressure pulse lithotripters – Characteristics of fields*

3 Terms and definitions

For the purposes of this document, the following terms and definitions as well as the definitions of IEC 60050-801 and IEC 60050-802 apply.

3.1

acoustic streaming

bulk fluid motion initiated by a sound field

3.2

free field

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

[IEV 801-23-28, modified]

3.3

output power

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

Symbol: P

Unit: watt, W

3.4

radiation force

acoustic radiation force

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

Symbol: F

Unit: Newton, N

3.5**radiation pressure****acoustic radiation pressure**

radiation force per unit area

NOTE This term is widely used in the literature. However, strictly speaking, the radiation force per unit area is a tensor quantity [4] and it should be referred to as the acoustic radiation stress tensor when a strict scientific terminology is to be used. The integral quantity "acoustic radiation force" is generally preferred in this International Standard. Whenever at some places the term "acoustic radiation pressure" appears, it is to be understood as the negative value of the normal radiation stress in the direction of the field axis.

Unit: Pascal, Pa

3.6**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**

3.7**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

3.8**radiation conductance**

ratio of the acoustic **output power** and the squared RMS transducer input voltage. It is used to characterize the electrical to acoustical transfer of **ultrasonic transducers**

Symbol: G

Unit: siemens, S

4 List of symbols a radius of a source **ultrasonic transducer** c speed of sound (usually in water) d geometrical focal length of a focused **ultrasonic transducer** F **radiation force** on a **target** in the direction of the incident ultrasonic wave g acceleration due to gravity G **radiation conductance** k circular wavenumber ($2\pi/\lambda$) P **output power** of an **ultrasonic transducer** s normalized distance from an **ultrasonic transducer** ($s = z \lambda / a^2$) z distance between a **target** and an **ultrasonic transducer** α amplitude attenuation coefficient of plane waves in a medium (usually water) γ focus (half-)angle of a focused **ultrasonic transducer** ($\arcsin a/d$) θ angle between the direction of the incident ultrasonic wave and the normal to a reflecting surface of a **target** λ ultrasonic wavelength 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 Requirements for radiation force balances

5.1 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 ultrasonic power shall be determined from the difference between the force measured with and without ultrasonic radiation, in accordance with the formulae given in Annex B. Calibration can be carried out by means of small precision weights of known mass.

NOTE Different possible radiation force measurement set-ups are presented in Figures F.1 to F.7. Each measurement set-up has its own merits, which are also summarised in Annex F.

5.2 Target type

5.2.1 General

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.)

If the target is chosen so as to closely approach one of the two extreme cases, i.e. perfect absorber or perfect reflector, the appropriate formula of Annex B shall be used depending on the field structure and the following requirements shall apply:

5.2.2 Absorbing target

An absorbing **target** (see Figure 1, F.1a, F.3, F.4, F.5a and F.7) shall have:

- an amplitude reflection factor of less than 3,5 %;
- an acoustic energy absorption within the **target** of at least 99 %.

(See also A.5.2.2.)

5.2.3 Reflecting target

A reflecting **target** (see Figure F.1b, F.2, F.5b and F.6) shall have:

- an amplitude reflection factor of greater than 99 %.

A conical reflecting target should not be used for power measurements of transducers where $ka < 30$. A convex-conical reflector with a cone half-angle of 45° shall not be used for power measurements of transducers where $ka < 17,4$, which follows from theoretical consideration of the effects of beam divergence. See also A.5.3.

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.

In addition, a convex-conical reflector with a cone half-angle of 45° should not be used for power measurements of focused transducers where $d < 32a$. If the geometrical focal length d is not known, then a convex-conical reflector with a cone half-angle of 45° should not be used when the distance z_f of the pressure maximum from the transducer is $z_f < 1/((1/32a) + (\lambda/a^2))$.

NOTE 2 This condition recommends to restrict the use of convex-conical reflectors to the unfocused case or the case of weak focusing, and this is in line with the restriction to "preferably well-collimated beams" in the Scope. If, nevertheless, a convex-conical reflector is used in strongly focused fields and formula (B.5) is applied, additional uncertainties that are not covered by Clause 7 need to be taken into account.

(See also A.5.2.3 and B.6.)

5.3 Target diameter

The **target** diameter shall be large enough to intercept all significant parts of the field. As a general requirement, it shall in no case be lower than 1,5 times the appropriate dimension (e.g. the diameter) of the **ultrasonic transducer**.

Whether or not the target diameter should be more than 1,5 times the transducer diameter, depends on the beam diameter of the field at the particular location of the target. The beam dimensions shall be measured or calculated from theoretical estimation as given, for example in A.5.3.

5.4 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 Vertical beam orientation allows traceability to national mass standards (calibrated weights). Set-ups with horizontal beam orientation exist in practice using either a reflecting target [5,6] or an absorbing target [7]. Calibration 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)

5.5 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 1 % of the overall measured power. (See also A.5.5.)

5.6 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 to less than 1 % of the overall measured power. (See also A.5.6.)

5.7 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 1 %.

5.8 Anti-streaming foils

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** [8]. Its transmission coefficient shall be known from measurement and a correction shall be applied, if its influence is more than 1 % of the overall measured power. (See also A.5.8.)

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

5.9 Transducer coupling

The **ultrasonic** transducer shall be coupled to the measurement device such that the impact on the overall measured power is less than 1 %, otherwise a correction shall be applied. (See also A.5.9.)

5.10 Calibration

The **radiation force** balance shall be calibrated by the use of small weights of known mass. Also, the **radiation force** balance should be calibrated by use of an ultrasonic source of known output power. In this case, the calibration shall be undertaken once every two years or more frequently if there is any indication that the balance sensitivity to ultrasonic power has changed.

6 Requirements for measuring conditions

6.1 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 1 %. (See also A.6.1.)

6.2 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 1 %. (See also A.6.2.)

6.3 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 Annex D. Where degassed water is required, the amount of dissolved oxygen in the water shall be <4 mg/l during all measurements.

(See also A.6.3.)

6.4 Water contact

Before starting the measurements, it shall be ensured that all air bubbles are removed from the active faces. After measurements are completed, the active faces shall again be inspected, and the measurements shall be discarded if any air bubbles are found. (See also A.6.4.)

6.5 Environmental conditions

For measurements in the milliwatt and microwatt region, either the measuring device shall be provided with thermal isolation or the measurement process, including data acquisition, shall be performed in such a way that thermal drift and other disturbances during the measurement cause no more than a 1 % effect on the overall measured power.

The measuring device shall be protected against environmental vibrations and air flow.

(See also A.6.5.)

6.6 Thermal drifts

When using an absorbing **target**, an estimate of the thermal effects due to the absorbed sound energy (expansion and buoyancy change) shall be made by recording the measured signal before and after the switch-on and switch-off of the **ultrasonic transducer**. (See also A.6.6.)

7 Measurement uncertainty

7.1 General

An estimation of the overall measurement uncertainty or accuracy assessment shall be determined individually for each set-up used. This assessment should include the following elements.

The uncertainty shall be assessed using the ISO Guide [9].

7.2 Balance system including target suspension

The balance system shall be checked or calibrated using small weights of known mass with the whole system prepared for radiation force measurements, including with the **target** suspended in water.

This procedure shall be repeated several times with each weight to obtain an indication of the random scatter of results. An uncertainty estimate for the balance calibration factor shall be derived from the results of this calibration and from the mass uncertainty of the weights used.

The results of these checks should be filed in order to enable a judgement of the long-term stability of the balance calibration factor.

(See also A.7.2.)

7.3 Linearity and resolution of the balance system

The linearity of the balance system shall be checked at least every six months as follows.

The measurements described in 7.2 shall be made with at least three weights of different masses within the balance output range of interest. The balance readout as a function of input mass can be represented as a graph in accordance with Figure 2. The resulting points of this graph should ideally be on a straight line starting at the origin of the coordinates. If deviations from this line occur, an additional uncertainty contribution shall be derived from them.

Since weights of less than 10 mg are difficult to handle, the balance linearity can also be checked by means of an **ultrasonic transducer** with known properties, activated by various levels of voltage amplitude and thus producing radiation forces of various magnitudes. In this case the input quantity at the abscissa of Figure 2 is the ultrasonic **output power** of the transducer, and its uncertainty shall be taken into account.

The limited resolution of the balance leads to a power uncertainty contribution that needs to be taken into account in the uncertainty analysis.

7.4 Extrapolation to the moment of switching the ultrasonic transducer

In the case of an electronic balance, to obtain the **radiation force** value, the balance output signal is typically recorded as a function of time and extrapolated back to the moment of switching the **ultrasonic transducer**. This extrapolation involves an uncertainty, depending mainly on the amount of scatter in the balance output signal (signal-to-noise ratio). The uncertainty of the extrapolation result shall be estimated by means of standard mathematical procedures in utilizing the regression algorithm.

7.5 Target imperfections

The influence of the **target** imperfections shall be estimated using a plane-wave approach such as described in A.7.5.

7.6 Reflecting target geometry

The influence of the reflecting **target** geometry shall be estimated and incorporated into the overall system uncertainty. (See A.7.6)

7.7 Lateral absorbers in the case of reflecting target measurements

The imperfections of the lateral absorbers in the arrangement of Figure F.1b, F.2, F.5b and F.6 shall be estimated and incorporated into the overall system uncertainty. (See also A.7.7.)

7.8 Target misalignment

The influence of **target** misalignment shall be estimated and incorporated into the overall system uncertainty. (See A.7.8)

7.9 Ultrasonic transducer misalignment

The influence of **ultrasonic transducer** misalignment shall be estimated and incorporated into the overall system uncertainty. (See A.7.9)

7.10 Water temperature

The uncertainty caused by water temperature shall be estimated and incorporated into the overall system uncertainty. (See A.7.10)

7.11 Ultrasonic attenuation and acoustic streaming

The uncertainty caused by ultrasonic attenuation and acoustic streaming shall be estimated and incorporated into the overall system uncertainty. (See A.7.11)

7.12 Foil properties

If a coupling foil or a shielding foil is used during the **radiation force** measurements, the foil transmission loss as measured or estimated shall be taken into account, as well as any possible effect of the reflected wave on the **ultrasonic transducer**. The uncertainty introduced by these effects shall be assessed individually and incorporated into the overall system uncertainty.

7.13 Finite target size

The effect on uncertainty of the finite target size shall be determined and included in the overall system uncertainty. (See A.7.13)

7.14 Plane-wave assumption

The uncertainty contribution due to the use of a plane-wave assumption shall be determined and included in the overall system uncertainty. (See A.7.14)

7.15 Environmental influences

The uncertainties caused by environmental vibrations, air flow or temperature variations shall be estimated and incorporated into the overall system uncertainty. (See A.7.15)

7.16 Excitation voltage measurement

If the excitation voltage applied to the **ultrasonic transducer** is measured and its value is of relevance to the result of the ultrasonic power measurement, its measurement uncertainty shall be estimated and incorporated into the overall system uncertainty. (See also A.7.16.)

7.17 Ultrasonic transducer temperature

If ultrasonic power values measured at different temperatures are to be compared, the dependence of the power on the temperature shall be checked and its influence be taken into account. (See also A.7.17.)

7.18 Non-linearity

The potential influence of non-linearities regarding the following shall be assessed and, if necessary, included in the overall system uncertainty:

- a) the linearity of the balance system including the **target** suspension;
- b) non-linear contributions due to improperly degassed water;
- c) ultrasonic attenuation and **acoustic streaming**;
- d) the theoretical **radiation force** relations themselves.

(See A.7.18)

7.19 Other sources

Checks should be performed periodically to determine whether the overall uncertainty as specified in 7.2 to 7.18 using the above guidelines is not influenced by any other sources of random scatter. (See also A.7.19.)