

Australian/New Zealand Standard™

**Ultrasonic power measurement in
liquids in the frequency range 0.5 MHz
to 25 MHz**



Standards Australia



STANDARDS
NEW ZEALAND

Documents



Document Sharing Hub

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee HE/3, Medical Electrical Equipment. It was approved on behalf of the Council of Standards Australia on 15 January 2000 and on behalf of the Council of Standards New Zealand on 25 February 2000. It was published on 20 April 2000.

The following interests are represented on Committee HE/3:

Australasian College of Physical Scientists and Engineers in Medicine
Australasian Society for Ultrasound in Medicine
Australian Dental Association
Australian Institute of Radiography
Australian Radiation Laboratory
Australian Society of Anaesthetists
College of Biomedical Engineering Institution of Engineers Australia
Commonwealth Department of Health and Family Services
Department of Defence (Australia)
Medical Industry Association of Australia
Ministry of Commerce, New Zealand
Royal Australasian College of Surgeons
Royal Australasian College of Radiologists

Keeping Standards up-to-date

Standards are living documents which reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued. Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments which may have been published since the Standard was purchased.

Detailed information about joint Australian/New Zealand Standards can be found by visiting the Standards Australia web site at www.standards.com.au or Standards New Zealand web site at www.standard.co.nz and looking up the relevant Standard in the on-line catalogue.

Alternatively, both organizations publish an annual printed Catalogue with full details of all current Standards. For more frequent listings or notification of revisions, amendments and withdrawals, Standards Australia and Standards New Zealand offer a number of update options. For information about these services, users should contact their respective national Standards organization.

We also welcome suggestions for improvement in our Standards, and especially encourage readers to notify us immediately of any apparent inaccuracies or ambiguities. Please address your comments to the Chief Executive of either Standards Australia International or Standards New Zealand at the address shown on the back cover.

Australian/New Zealand Standard™

Ultrasonic power measurement in liquids in the frequency range 0.5 MHz to 25 MHz

First published as AS/NZS 4714:2000.

COPYRIGHT

© Standards Australia/Standards New Zealand

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher.

Jointly published by Standards Australia International Ltd, PO Box 1055, Strathfield, NSW 2135 and Standards New Zealand, Private Bag 2439, Wellington 6020

ISBN 0 7337 3245 3

PREFACE

This Standard was prepared by the Joint Australian/New Zealand Standards Committee HE/3, Medical Electrical Equipment.

This Standard is issued as a necessary adjunct to the following to-be-published Joint Standards—
Ultrasonics—Physiotherapy systems, Part 1: Guide for physiotherapists checking calibration; and
Ultrasonics—Physiotherapy systems, Part 2: Guide for commercial testers checking calibration,
and is an integral part of the calibration process.

This Standard is identical with and has been reproduced from IEC 61161:1992, *Ultrasonic power measurement in liquids in the frequency range 0.5 MHz to 25 MHz* and its first Amendment (1998). The amendment follows the text of the Standard and changes required are indicated in the IEC text by a marginal bar against the clause, table, figure or part thereof affected.

None of the Standards referred to in Clause 2 have been issued as Australian/New Zealand publications.

As this publication has been reproduced from an international Standard, the following modifications apply:

- (a) Its number does not appear on each page of text and its identity is shown on the cover and title page.
- (b) The words ‘this Australian/New Zealand Standard’ should replace the words ‘this International Standard’ wherever they appear.
- (c) Substitute a full point for a comma where it appears as a decimal marker.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the Annex to which they apply. A ‘normative’ Annex is an integral part of a Standard, whereas an ‘informative’ Annex is only for information and guidance.

CONTENTS

Clause		Page
	INTRODUCTION	iv
1	Scope	1
2	Normative references	1
3	Definitions.....	1
4	List of symbols	2
5	Requirements for radiation force balances	3
5.1	General.....	3
5.2	Target type	3
5.3	Target diameter	4
5.4	Microbalance/Force measuring system	4
5.5	System tank	5
5.6	Target support structures	5
5.7	Transducer positioning.....	5
5.8	Anti-streaming foils	6
5.9	Transducer coupling.....	6
5.10	Calibration	6
6	Requirements for measuring conditions	7
6.1	Lateral transducer position	7
6.2	Transducer/Target separation	7
6.3	Water.....	7
6.4	Water contact	8
6.5	Environmental conditions	8
6.6	Thermal drifts.....	8
7	Measurement uncertainty	8
7.1	Assessment of measurement uncertainties.....	8
	Figures.....	14
	Annex A – Basic formulae.....	17
	Annex B – Other methods of ultrasonic power measurement	19
	Annex C – Bibliography.....	20

INTRODUCTION

A number of measuring methods exist for the determination of the total radiated power of ultrasonic transducers ([1]* to [3]*, see also annex B). The purpose of this International Standard is to establish methods of measurement of ultrasonic power in liquids in the 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. In addition, the radiation force measuring devices are easy to handle and to calibrate.

This standard enumerates the sources of errors and describes a systematic step-by-step procedure needed to assess overall measurement uncertainties.

AUSTRALIAN/NEW ZEALAND STANDARD

Ultrasonic power measurement in liquids in the frequency range 0.5 MHz to 25 MHz

1 Scope

This International Standard

- specifies a method of determining the total radiated 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.

NOTE – The radiation force is equal to the change in the time-averaged momentum flow and is thus related to ultrasonic intensity and power.

- provides information on assessment of overall measurement uncertainties.

This International Standard is applicable to:

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

NOTE – The titles of other publications referred to in this Standard are listed in annex C.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(801):1984, *International Electrotechnical Vocabulary (IEV) – Chapter 801: Acoustics and electro-acoustics*

IEC 60150:1963, *Testing and calibration of ultrasonic therapeutic equipment*

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

3 Definitions

3.1 acoustic streaming: Steady-state fluid motion which develops under certain conditions in a sound field.

3.2 far field: Sound field at a distance from the source where the sound pressure decreases monotonically with increasing distance from the source. In general, this is the region of the sound field where the specific acoustic impedance, i.e. the complex ratio of sound pressure to particle velocity, is substantially equal to ρc , ρ being the density and c the velocity of sound in the sound-propagating medium.

3.3 free field: A sound field in a homogeneous isotropic medium whose boundaries exert a negligible effect on the sound waves. [IEV 801-03-28 modified.]

3.4 near field: Sound field at distances from the source smaller than the distance at which the **far field** begins. In general, this is the region of the sound field where the complex specific acoustic impedance differs appreciably from ρc .

3.5 output power: Time-average ultrasonic power radiated by an **ultrasonic transducer** into an approximately **free field** under specified conditions in a specified medium, preferably water.

Symbol: P

Unit: watt, W

3.6 radiation force; acoustic radiation force: Time-average force acting on a body in a sound field and caused by the sound field; or, more generally: time-average force in a sound field, appearing at the boundary surface between two media of different acoustic properties.

Symbol: F

Unit: newton, N

3.7 radiation pressure; acoustic radiation pressure: Radiation force per unit area.

3.8 target: A device specially designed to be inserted into the ultrasonic field and to serve as the object on which the **radiation force** is to be measured.

3.9 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.

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 propagation direction of an ultrasonic wave

g = acceleration due to gravity

k = $(= 2\pi/\lambda)$ circular wavenumber

P = **output power** of an **ultrasonic transducer**

s = $(= x \lambda/a^2)$ distance normalized to the **near-field** length

x = distance between a **target** and an **ultrasonic transducer**

α = amplitude attenuation coefficient of plane waves in a medium (usually water)

γ $(= \arcsin a/d)$ focus angle of a focused **ultrasonic transducer**

θ = angle between propagation direction of an ultrasonic wave and the normal to a reflecting surface of a **target**

λ = ultrasonic wavelength.

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 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, according to the formulae given in annex A. Calibration can be carried out by means of small precision weights of known mass.

5.2 Target type

The **target** shall have known acoustic properties, these being relevant to the details of the relation between ultrasonic power and **radiation force**. Usually, the aim is to approach most closely one of the two extreme cases: perfect absorber or perfect reflector [4]. The compressibility should be as low as possible in order to avoid buoyancy changes due to variations of the ambient pressure. Care should be taken in other respects to maximize the stability of buoyancy of the **target**.

5.2.1 Absorbing target

An absorbing **target** (see figure 1) shall have:

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

Circular discs of appropriate elastic rubber material with or without wedges are normally used as absorbing **targets**. To increase the absorbing properties, the material should contain inhomogeneities.

Figure 2 shows an example of a set-up of a wedge-type absorber. In this case the concentration of the inhomogeneities increases from zero at the wedges to 30 % by volume at the rear surface. Hollow glass spheres of diameter of the order of one-tenth millimetre behave satisfactorily as inhomogeneities, since they have only little influence on the density and compressibility of the elastic rubber material.

5.2.2 Reflecting target – General

The main problem is to reduce the compressibility of a reflecting **target** because air pressure fluctuations modulate the volume, and thereby the buoyancy of the **target**, proportional to its compressibility. Plane sound reflectors which are normally realized by means of air-backed thin metal plates cannot be applied. Using solid metal plates as reflectors, that are adjusted under an angle of 45° to the sound beam axis, may cause an enormous error [5].

Cone-shaped reflectors made of thick-walled hollow bodies or of air-backed thin metal plates are applicable. Cone-shaped reflectors made of very stiff plastic foam and which are coated with a very thin metal layer produced by electroplating have proved to be adequate **targets** [4].

5.2.3 Reflecting target – convex

A conical reflector of the convex type is shown in figure 3. The cone half-angle is typically chosen to be 45°, so that the reflected wave leaves at right angles to the ultrasound beam axis.

5.2.4 Reflecting target – concave

A conical reflector of the concave type is shown in figure 4. The cone half-angle is typically chosen to be of the order of 60° to 65°, so that the reflected wave is directed nearer to the **ultrasonic transducer** than with the convex-type reflector.

5.3 Target diameter

The **target** diameter shall be large enough to intercept all significant parts of the field, and shall be at least 1,5 times larger than the appropriate dimension (e.g. the diameter) of the **ultrasonic transducer**. The necessary diameter value depends on the field structure and on the distance of the **target** from the **ultrasonic transducer**.

In the following, an assessment formula [6] is given for the minimum value of the **target** radius b which would lead to a **radiation force** which amounts to at least 98 % of the **radiation force** that would exist if the **target** were of infinite cross-sectional size (i.e. giving an error of less than 2 %). The equation is valid for an absorbing circular **target** in the field of a continuously vibrating, baffled circular plane piston **ultrasonic transducer** of radius a in a non-absorbing medium. The formula is:

$$b = a [1/(1 + 0,53 \tau_1 s) + \tau_1 s] \quad (1)$$

with

$$\beta = 0,98 + 0,01 \pi k a$$

$$\tau_1 = \tau_0 + \Delta \tau$$

$$\tau_0 = k a / (2\pi (\beta^2 - 1)^{1/2})$$

$$\Delta \tau = \begin{cases} 0,7 & \text{if } k a \leq 9,3 \\ 6,51 / k a & \text{if } 9,3 \leq k a \leq 65,1 \\ 0,1 & \text{if } 65,1 \leq k a \end{cases}$$

where

x is the distance between the **target** and the **ultrasonic transducer**;

λ is the ultrasonic wavelength in the propagation medium;

$k = 2\pi/\lambda$ is the circular wavenumber;

$s = x \lambda / a^2$ is the distance between the **target** and the **ultrasonic transducer** normalized to the **near-field** length.

Equation (1) can also be solved for s , yielding a maximum value of the normalized distance between the **target** and the **ultrasonic transducer** for a **target** of given radius b . The influence of absorption and **acoustic streaming** is considered separately.

By way of precaution, b should never be reduced below 1,5 a , even if this were possible according to the above equation.

5.4 Microbalance/Force measuring system

The **radiation force** balance is understood in this standard to be a gravimetric balance and, hence, the beam orientation is vertical.

NOTE – A horizontal beam orientation may potentially be of interest since thermal effects, such as convection currents and changes in buoyancy, should be reduced in that case. A measurement set-up with horizontal beam orientation is described in [7].

The type of balance needed depends strongly on the magnitude of the ultrasonic power to be measured. A power value of 10 mW is equivalent to a **radiation force** (in water on an absorbing **target**) of 6,7 μN corresponding to a mass equivalent of 0,68 mg, whereas a power value of 10 W means a **radiation force** of 6,7 mN corresponding to a mass equivalent of 0,68 g. In the former case, an electronic, self-compensating microbalance is the most suitable instrument, whereas in the latter case, an appropriate electronic balance or a purely mechanical laboratory balance [8] may be used. In any case, compensation of the **target** displacement at the position of rest is essential.

If the balance/force measuring device is calibrated by means of small weights of known mass or if for other reasons, the readout of the balance/force-measuring device is given in mass units, the measurement result in mass units is to be multiplied by the acceleration due to gravity $g = 9,81 \text{ m} \cdot \text{s}^{-2}$, in order to convert it into a force. If the measurement result is given in milligrams (or grams), multiplication by g yields a force in micronewtons (or in millinewtons, respectively). When the force is converted to ultrasonic power according to the formulae given in annex A, the use of a sound velocity value in metres per second, as for example $c = 1\,491 \text{ m} \cdot \text{s}^{-1}$ in pure water at 23 °C, then yields a power in microwatts (or in milliwatts, respectively).

5.5 System tank

If a reflecting **target** is used, an absorbing lining of the measuring vessel shall be used.

It is necessary to ensure that neither the **target** nor any other parts of the measuring device give rise to any substantial ultrasonic reflections, or that the reflections are emitted in such directions that they do not return to the **ultrasonic transducer** and react on it. Otherwise, the measured power will not in general be equal to the desired **freefield** value.

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 should be designed to minimize the effect of surface tension.

If the **target** is suspended by wires which penetrate the liquid surface then they should have a diameter as small as possible to reduce measurement errors, that may be caused by incomplete wetting of the wire or by dust particles. Disturbing forces may be of the order of 0,1 μN . The use of a small wire diameter is even more important in a situation where the **ultrasonic transducer** is placed above the **target** (radiation downwards) and where several suspension wires may be needed, as in figure 4.

NOTE – Platinum-iridium wire of diameter 50 μm is suitable.

5.7 Transducer positioning

The **ultrasonic transducer** mount shall be such as to ensure stable and reproducible positioning of the **ultrasonic transducer** with respect to the **target**.

5.8 Anti-streaming foils

If the energy absorption along the sound path cannot be neglected (long sound path and/or high frequency [9]) **acoustic streaming** can take place.

To reduce streaming effects in the measuring liquid, thin plastic foils are often put into the sound path. When using these foils two boundary conditions shall be fulfilled : the foil shall be positioned close to the **target** and shall not be oriented parallel to the surface of the **ultrasonic transducer** [10].

Two types of streaming can be relevant: the heat convection type, as for example in the case of an **ultrasonic transducer** warm-up during ultrasonic operation, and the **acoustic streaming** which is associated with ultrasonic attenuation and, hence, occurs primarily in the high-frequency range.

If a foil is used its thickness shall be as small as possible in order to optimize its transmitting properties. This aspect is of major concern at high frequencies. The transmission coefficient should be known from theory or experiment and a correction shall be applied if its influence is too high.

The foil shall be positioned at a slightly oblique angle in order to prevent the reflected ultrasonic wave from arriving at the **ultrasonic transducer** with a phase which is constant all over the **ultrasonic transducer** surface [10].

5.9 Transducer coupling

For precision measurements, the **ultrasonic transducer** should be coupled directly to the measurement liquid in order to avoid an impedance transformation by an additional coupling foil. This is particularly important for very sensitive high accuracy balances in which the ultrasonic beam is directed vertically upwards [11], [12] (figures 1 and 3). Avoiding the impedance transformation caused by the addition of a coupling foil is particularly important in measurements on high-Q **ultrasonic transducers**.

NOTE – An air-backed **ultrasonic transducer**, for example, can be strongly affected by surface pressure.

Detailed technical drawings of a proven device for convenient measurements with a coupling membrane are given in [13]. They should work well for most practical measurements on broadband **ultrasonic transducers** provided that the anti-streaming foil is appropriately positioned as required in 5.8 and that its effectiveness is independently verified.

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 transducer** 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.