IEC TS 63001

Edition 2.0 2024-02

TECHNICAL SPECIFICATION

colour inside

Measurement of cavitation noise in ultrasonic baths and ultrasonic reactors



IEC TS 63001:2024-02(en)

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2024 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews, graphical symbols and the glossary. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 500 terminological entries in English and French, with equivalent terms in 25 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC TS 63001

Edition 2.0 2024-02

TECHNICAL SPECIFICATION

colour inside

Measurement of cavitation noise in ultrasonic baths and ultrasonic reactors

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.140.01; 17.140.50

ISBN 978-2-8322-8118-5

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms and definitions 7
4 List of symbols 11
5 Measurement equipment 12
5.1 Hydrophone 12
5.1.1 General 12
5.1.2 Calibration of hydrophone sensitivity 12
5.1.3 Hydrophone properties 12
5.1.4 Hydrophone compatibility with environment 13
5.2 Analyser 13
5.2.1 General considerations 13
5.2.2 Specific measurement method: inertial cavitation spectrum measurement at frequencies between harmonics of f_0 14
5.2.3 Specific measurement method: Measurement of integrated broadband cavitation noise energy between two frequency bounds 14
5.2.4 Specific measurement method: cavitation noise measurement by extraction of broadband spectral components 15
5.3 Requirements for equipment being characterized 15
5.3.1 Temperature and chemistry compatibility with the hydrophone 15
5.3.2 Electrical interference 15
6 Measurement procedure 15
6.1 Reference measurements 15
6.1.1 Control of environmental conditions for reference measurements 15
6.1.2 Measurement procedure for reference measurements 16
6.2 In-situ monitoring measurements 16
Annex A (informative) Background 17
A.1 Cavitation in ultrasonic cleaning 17
A.2 Practical considerations for measurements 19
A.3 Measurement procedure in the ultrasonic bath 20
A.4 Characterization methods that do not utilize the acoustic spectrum 21
Annex B (normative) Cavitation noise measurement between harmonics of f_0 22
B.1 General 22
B.2 Measurement method 22
Annex C (informative) Example of cavitation noise measurement between harmonics of f_0 26
Annex D (normative) Measurement of integrated broadband cavitation noise energy between two frequency bounds 27
D.1 General 27
D.2 Measurement frequency range 27
D.3 Definition of integrated broadband cavitation noise energy 27
Annex E (informative) Example of measurement of integrated broadband cavitation noise energy between two frequency bounds 28
Annex F (normative) Cavitation noise measurement by extraction of broadband spectral components 31

F.1 Compensation for extraneous noise 31
F.2 Features of the acoustic pressure spectrum 31
F.3 Identification of the operating frequency f_0 and direct field acoustic pressure 32
F.3.1 Identification of the operating frequency f_0 32
F.3.2 Fit to primary peak (direct field) 32
F.3.3 Determination of RMS direct field acoustic pressure 32
F.3.4 Validation 32
F.4 Identification of cavitation noise components 32
F.4.1 Subtraction of direct field component of spectrum 32
F.4.2 Determination of non-broadband cavitation component 32
F.4.3 Determination of broadband cavitation component 33
F.4.4 Validation 33
Bibliography 34

Figure A.1 – Typical setup of an ultrasonic cleaning device 17
Figure A.2 – Spatial distribution of the acoustic pressure level in water in front of a 35 kHz transducer with reflections on all sides of the water bath (0,12 m × 0,3 m × 0,25 m) 18
Figure A.3 – Typical Fourier spectrum for sinusoidal ultrasound excitation above the cavitation threshold at an operating frequency of 35 kHz 18
Figure A.4 –Photograph of cavitation structure under the water surface at an operating frequency of 25 kHz 19
Figure A.5 – Typical rectangular ultrasound signal with a frequency of 25 kHz and 50 Hz double half wave modulation 20
Figure B.1 – Block diagram of the measuring method of the cavitation noise level L_{CN} 24
Figure C.1 – Power dependency of the cavitation noise level L_{CN} 26
Figure C.2 – Diagram with example of spectral acoustic pressure of an ultrasonic bath with an operating frequency of 46 kHz and its harmonics and sub-harmonics 26
Figure E.1 – Schematic of the cylindrical cavitation hollow cavitation sensor [27], [28] 28
Figure E.2 – High-frequency spectra obtained from the cavitation sensor of the type shown in Figure E.1 [28] for a commercial ultrasonic cleaning vessel operating at 40 kHz whose nominal power setting has been changed from 5 % to 95 % of its full operating power 29
Figure E.3 – Variation in the integrated broadband cavitation energy derived using the cylindrical cavitation sensor, from the acoustic spectra shown in Figure E.2 30
Figure E.4 – Raster scan covering a commercial ultrasonic cleaning vessel with four transducers operating at 40 kHz 30
Figure F.1 – Schematic representation of acoustic pressure spectrum $p_{RMS}(f)$ 31

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

MEASUREMENT OF CAVITATION NOISE IN ULTRASONIC BATHS AND ULTRASONIC REACTORS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 63001 has been prepared by IEC technical committee 87: Ultrasonics. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2019. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition of a new method of measurement: the measurement of integrated broadband cavitation energy between two frequency bounds.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
87/804/DTS	87/822A/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

Terms in **bold** in the text are defined in Clause 3.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Ultrasonically induced **cavitation** is used frequently for immersion cleaning in liquids. There are two general classes of ultrasonically induced cavitation. **Inertial cavitation** is the rapid collapse of bubbles. **Non-inertial cavitation** refers to persistent pulsation of bubbles as a result of stimulation by an ultrasonic field. Both **inertial cavitation** and **non-inertial cavitation** can create significant localized streaming effects that contribute to cleaning. **Inertial cavitation** additionally causes a localized shock wave that can contribute to cleaning and or damage of parts. Both types of cavitation create acoustic signals (**cavitation noise**) which can be detected and measured with a **hydrophone**. This document provides techniques to measure and evaluate the degree of cavitation in support of validation efforts for ultrasonic cleaning tanks, cleaning equipment, and reactors, as used, for example, for the purposes of industrial process control or for hospital sterilization.

MEASUREMENT OF CAVITATION NOISE IN ULTRASONIC BATHS AND ULTRASONIC REACTORS

1 Scope

This document, which is a Technical Specification, provides a technique of measurement and evaluation of ultrasound in liquids for use in cleaning devices, equipment, and ultrasonic reactors. It specifies

- the **cavitation** measurement at frequencies between harmonics of the **operating frequency** f_0,
- the **cavitation** measurement derived by integrating broadband cavitation noise energy,
- the **cavitation** measurement by extraction of broadband spectral components.

This document covers the measurement and evaluation of cavitation, but not its secondary effects (cleaning results, sonochemical effects, etc.). Further details regarding the generation of cavitation noise in ultrasonic baths and ultrasonic reactors are provided in Annex A.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
averaging time for cavitation measurement
t_{av}
length of time over which a signal is averaged to produce a measurement of cavitation

Note 1 to entry: Averaging time for cavitation is expressed in seconds (s).

Note 2 to entry: As cavitation is a stochastic process, integrating over a sufficiently large t_{av} can be necessary to generate stability of the readings. An example is given in Annex B under Formula (B.4).

3.2
cavitation
formation of vapour cavities in a liquid

3.3
cavitation noise
acoustic signals as measured by a **hydrophone**, arising from the presence of **cavitation** in a liquid, or the interaction of **cavitation** with the **direct field acoustic pressure** signal

3.4
inertial cavitation
sudden collapse of a bubble in a liquid in response to an externally applied acoustic field, such that an acoustic shock wave is created

3.5
non-inertial cavitation
oscillation in size or shape of a bubble in a liquid in response to an externally applied acoustic field that is sustained over multiple cycles of the driving frequency

3.6
end-of-cable loaded sensitivity
$\underline{M}_{\mathrm{L}}(f)$
<of a **hydrophone** or **hydrophone assembly**> quotient of the Fourier transformed **hydrophone** voltage-time signal $\mathcal{F}(u_{\mathrm{L}}(t))$ at the end of any integral cable or output connector of a **hydrophone** or **hydrophone assembly**, when connected to a specific **electric load impedance**, to the Fourier transformed acoustic pulse waveform $\mathcal{F}(p(t))$ in the undisturbed free field of a plane wave in the position of the reference centre of the **hydrophone** if the **hydrophone** were removed, at a specified frequency

$$\underline{M}_{\mathrm{L}}(f) = \frac{\mathcal{F}\left(u_{\mathrm{L}}(t)\right)}{\mathcal{F}\left(p(t)\right)}$$

Note 1 to entry: The Fourier transform is in general a complex-valued quantity but for this document only the modulus is considered, and is expressed in units of volt per pascal, V/Pa,

Note 2 to entry: The term "response" is sometimes used instead of "sensitivity".

[SOURCE: IEC 62127-3:2022, 3.7, modified – Only the modulus is considered, Note 1 to entry has been exchanged and Note 2 to entry has been added.] [2]

3.7
end-of-cable loaded sensitivity level
$L_{M_{\mathrm{L}}}(f)$
<of a hydrophone or hydrophone assembly> twenty times the logarithm to the base 10 of the ratio of the modulus of the **end-of-cable loaded sensitivity** $\left|\underline{M}_{\mathrm{L}}\right|$ to a reference sensitivity of M_{ref}

$$L_{M_{\mathrm{L}}}(f) = 20\log_{10}\frac{\left|\underline{M}_{\mathrm{L}}(f)\right|}{M_{\mathrm{ref}}}\,\mathrm{dB}$$

Note 1 to entry: A commonly used value of the reference sensitivity M_{ref} is 1 V/µPa.

Note 3 to entry: The **end-of-cable loaded sensitivity level** is expressed in decibels (dB).

[SOURCE: IEC 62127-1:2022, 3.26, modified – In the definition, a different symbol is used and "quotient" has been replaced with "ratio".

3.8
hydrophone
transducer that produces electric signals in response to pressure fluctuations in water

[SOURCE: IEC 60050-801:2021, 801-32-26] [1]

3.9
hydrophone assembly
combination of **hydrophone** and **hydrophone pre-amplifier**

[SOURCE: IEC 62127-3:2022, 3.13] [2]

3.10
number of averages
N_{av}
number of waveforms captured and averaged in a **cavitation** measurement

3.11
operating frequency
f_0
driving frequency of ultrasound generator

Note 1 to entry: Operating frequency is expressed in hertz (Hz).

3.12
relative cavitation noise measurements
measurements made for purposes of comparison between two different cleaning environments or different locations within a cleaning environment, such that the **end-of-cable loaded sensitivity of the hydrophone** can be assumed to be identical in both cases

3.13
sampling frequency
f_s
number of points per second captured by a digital waveform recorder

Note 1 to entry: Sampling frequency is expressed in hertz (Hz).

3.14
size of the capture buffer
N_{cap}
total number of points captured at a time by a digital waveform recorder

3.15
capture time
t_{cap}
length of time to capture N_{cap} points at a sampling frequency of f_s

Note 1 to entry: Capture time is expressed in seconds (s).

3.16
cavitation noise level
L_{CN}
level calculated from the cavitation noise at frequencies between harmonics of f_0

Note 1 to entry: Cavitation noise is expressed in decibels (dB).

3.17
integrated broadband cavitation noise energy
E_{IBCN}
cavitation noise energy integrated between two identified frequency bounds, f_u and f_l

Note 1 to entry: Commonly expressed in units of V^2s^{-1}.

3.18
reference sound pressure
p_{ref}
sound pressure, conventionally chosen, equal to 20 µPa for gases and to 1 µPa for liquids and solids

Note 1 to entry: Reference sound pressure is expressed in pascals (Pa).

[SOURCE: IEC 60050-801:1994, 801-21-22] [1]

3.19
averaged power spectrum
$\overline{P^2}(f)$
power spectrum of the **instantaneous acoustic pressure** averaged over N_{av} measurements

Note 1 to entry: Averaged power spectrum is expressed in units of Pa^2.

3.20
median of acoustic pressure
P_n
median value of amplitude values of spectral lines within B_f

Note 1 to entry: Median of acoustic pressure is expressed in pascals (Pa).

3.21
band filter
B_f
band filter located at a centre frequency which is between harmonics of f_0

Note 1 to entry: Band filter is expressed in hertz (Hz).

3.22
centre frequency
f_c
centre frequency of the band filter B_f

Note 1 to entry: Centre frequency is expressed in hertz (Hz).

3.23
direct field acoustic pressure
P_0
portion of the RMS acoustic pressure signal arising directly from the ultrasonic driving excitation, at the **operating frequency** of the device

Note 1 to entry: RMS direct field acoustic pressure is expressed in pascals (Pa).

3.24
spectral acoustic pressure
$P(f)$
discrete Fourier transform of the hydrophone voltage divided by the **end-of-cable loaded sensitivity**

Note 1 to entry: Spectral acoustic pressure is expressed in pascals (Pa).

3.25
non-broadband cavitation component
P_{nb}
portion of the RMS acoustic pressure signal arising **from non-inertial cavitation**

Note 1 to entry: The non-inertial cavitation component is expressed in pascals (Pa).

3.26
broadband cavitation component
P_b
portion of the RMS acoustic pressure signal arising from **inertial cavitation**

Note 1 to entry: The inertial cavitation component is expressed in pascals (Pa).

3.27
voltage
$u(t)$
instantaneous voltage measured by analyser

Note 1 to entry: Voltage is expressed in volts (V).

3.28
voltage spectrum
$U(f)$
discrete Fourier transform of the voltage

Note 1 to entry: Voltage spectrum is expressed in volts (V).

3.29
window function
$w(n)$
amplitude weighting function used in the discrete Fourier transform

3.30
frequency spacing
Δf
distance of spectrum samples of a discrete Fourier transform

Note 1 to entry: Frequency spacing is expressed in hertz (Hz).

4 List of symbols

f	frequency
f_0	**operating frequency**
f_l	lower frequency limit used on the calculation of the **integrated broadband cavitation noise energy**
f_s	**sampling frequency**
f_U	upper frequency limit used on the calculation of the **integrated broadband cavitation noise energy**
E_IBCN	**integrated broadband cavitation noise energy**
$M_\mathrm{L}(f)$	**end-of-cable loaded sensitivity**
N_av	number of averages
N_cap	**number of points captured in a waveform**
t_cap	**capture time**
$P(f)$	**spectral acoustic pressure** (a function of frequency)
$P_0(f)$	**direct field acoustic pressure**
$P_\mathrm{nb}(f)$	**non-broadband cavitation component**
$P_\mathrm{b}(f)$	**broadband cavitation component**
$u(t)$	**voltage** (a function of time)
$U(f)$	**voltage spectrum** (a function of frequency)
L_CN	**cavitation noise level**
p_ref	**reference sound pressure**
$\overline{P^2}(f)$	**averaged power spectrum**
P_n	**median of acoustic pressure**
B_f	**band filter**