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TECHNICAL SPECIFICATION

colour inside

**Marine energy – Wave, tidal and other water current converters –
Part 40: Acoustic characterization of marine energy converters**

IEC TS 62600-40:2019-06(en)

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MARINE ENERGY – WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS –

Part 40: Acoustic characterization of marine energy converters

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62600-40, which is a Technical Specification, has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

The text of this Technical Specifications based on the following documents:

Draft TS	Report on voting
114/297/DTS	114/307/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62600 series, published under the general title *Marine energy – Wave, tidal and other water current converters*, can be found on the IEC website.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

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

The purpose of this document is to provide uniform methodologies that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions from marine energy converters. These systems include wave, current (tidal, ocean, and river), and ocean thermal energy conversion. The document provides guidance on the measurement, analysis, and reporting of acoustic emissions from marine energy converters and has been prepared with the anticipation that it would be applied by:

- Marine energy converter manufacturers striving to meet well-defined acoustic emission performance requirements and/or a possible declaration system;
- Purchasers of marine energy converters to specify such performance requirements;
- Operators of marine energy converters who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- Operators of marine energy test sites, who may be required to assess conformity with consented acoustic levels at their sites;
- Marine energy converter planners or regulators who must be able to accurately and fairly define acoustical emission characteristics of marine energy converters in response to environmental regulations or permit requirements for new or modified installations.

The methods and reporting requirements in this document ensure that continuing development and operation of marine energy converters is carried out in an atmosphere of consistent and accurate communication relative to environmental concerns.

MARINE ENERGY – WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS –

Part 40: Acoustic characterization of marine energy converters

1 Scope

This part of IEC 62600 provides uniform methodologies to consistently characterize the sound produced by the operation of marine energy converters that generate electricity, including wave, current, and ocean thermal energy conversion. This document does not include the characterization of sound associated with installation, maintenance, or decommissioning of these converters, nor does it establish thresholds for determining environmental impacts. Characterization refers to received levels of sound at particular ranges, depths, and orientations to a marine energy converter. Informative Annex B provides guidance on additional measurements that would be necessary to estimate source levels.

The scope of this document encompasses methods and instrumentation to characterize sound near marine energy converters, as well as the presentation of this information for use by regulatory agencies, industry, and researchers. Guidance is given for instrumentation calibration, deployment methods around specific types of marine energy converters, analysis procedures, and reporting requirements.

This document is applicable to characterization of sound from individual converters and arrays. This document primarily describes measurement procedures for individual converters, with extension to arrays discussed in informative Annex A.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60565, *Underwater acoustics – Hydrophones – Calibration in the frequency range 0,01 Hz to 1 MHz*

IEC 61108-4, *Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) – Part 4: Shipborne DGPS and DGLONASS maritime radio beacon receiver equipment – Performance requirements, methods of testing and required test results*

IEC 61400-12-1, *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC TS 62600-1, *Marine energy – Wave, tidal and other water current converters – Part 1: Terminology*

IEC TS 62600-20, *Marine energy – Wave, tidal and other water current converters – Part 20: Design and analysis of an Ocean Thermal Energy Conversion (OTEC) plant – General guidance*

IEC TS 62600-100, *Marine energy – Wave, tidal and other water current converters – Part 100: Electricity producing wave energy converters – Power performance assessment*

IEC TS 62600-200, *Marine energy – Wave, tidal and other water current converters – Part 200: Electricity producing tidal energy converters – Power performance assessment*

ISO 17208-1, *Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: Requirements for precision measurements in deep water used for comparison purposes*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 62600-1 and the following 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
acoustic self-noise
sound at a receiver caused by the deployment, operation, or recovery of the receiver, and its associated platform

[SOURCE: ISO 18405:2016, 2.1.1.5]

3.2
ambient noise
all sound, except **acoustic self-noise** and sound associated with a specified signal

[SOURCE: ISO 18405:2016, 2.1.1.6, modified – Notes not relevant to this document have been removed.]

3.3
flow-noise
non-acoustic pressure fluctuations measured by a pressure-sensitive instrument

Note 1 to entry: This is sometimes referred to as “hydrodynamic noise”.

Note 2 to entry: Moving water can also excite structures, causing them to radiate acoustic pressure, but this is categorized as acoustic self-noise.

3.4
mean-square sound pressure spectral density
distribution as a function of frequency of the mean-square sound pressure per unit bandwidth of a sound having a continuous spectrum

Note 1 to entry: Mean-square sound pressure spectral density is expressed in units of pascal squared per hertz (Pa^2/Hz).

Note 2 to entry: For operational purposes, mean-square sound pressure spectral density is estimated as the mean-square sound pressure in a finite frequency band divided by the frequency bandwidth. The averaging time and frequency band shall be specified.

[SOURCE: ISO 18405: 2016, 2.1.3.13, modified – Notes 2, 4, and 5, which are not relevant to this document, have been removed, as has the preferred formula.]

3.5
mean-square sound pressure spectral density level
ten times the logarithm to the base 10 of the ratio of the **mean-square sound pressure spectral density** to the specified reference value, in decibels

Note 1 to entry: Mean-square sound pressure spectral density level is the level of the power quantity mean-square sound pressure spectral density.

Note 2 to entry: Mean-square sound pressure spectral density level is expressed in decibels.

Note 3 to entry: In underwater acoustics, the reference value of mean-square sound pressure spectral density is 1 $\mu Pa^2/Hz$.

[SOURCE: ISO 18405:2016, 2.2.1.10, modified – Symbolic notation and formulas from the definition and Notes 1 and 3 have been removed and Note 4 has been removed because it is not relevant to this document.]

3.6
marine energy converter sound pressure level
ten times the logarithm to the base 10 of the ratio of the integrated mean-square sound pressure spectral density over the measurement frequency range to the specified reference value, in decibels

Note 1 to entry: Marine energy converter sound pressure level is expressed in decibels.

Note 2 to entry: The reference value is 1 μPa^2 – see: mean-square sound pressure spectral density level.

3.7
decidecade sound pressure level
ten times the logarithm to the base 10 of the ratio of the integrated **mean-square sound pressure spectral density** over a specified decidecade frequency band to the specified reference value, in decibels

Note 1 to entry: The frequency ratio corresponding to a decidecade (1 ddec) is $10^{0,1}$. One decidecade (0,1dec) is equal to 0,1 $\log_2(10)$.

Note 2 to entry: Decidecade bands are defined in IEC 61260-1:2014 as "one-third octave bands".

Note 3 to entry: Decidecade sound pressure level is expressed in decibels (dB).

Note 4 to entry: The reference value is 1 μPa^2 – see: mean-square sound pressure spectral density level.

3.8
sound pressure
difference between instantaneous total pressure and pressure that would exist in the absence of sound waves

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

[SOURCE: ISO 18405:2016, 2.1.2.1, modified – Notes 2, 3, 4, and 5, which are not relevant to this document, have been removed, the preferred formula has been removed, and it has been made explicit that this is an instantaneous quantity.]

3.9
self-noise
fluctuations in signal caused by the combination of **acoustic self-noise** and non-acoustic self-noise

Note 1 to entry: An example of acoustic self-noise is hydrodynamic excitation of the sound measurement system that generates propagating sound.

Note 2 to entry: An example of non-acoustic self-noise is electrical noise internal to the sound measurement system electronics.

[SOURCE: ISO 18405:2016, 2.6.1.6, modified – Note 1, which is not relevant to this document, has been removed and notes have been added with examples of acoustic self-noise and non-acoustic self-noise.]

4 Symbols and abbreviated terms

H_{m0}	significant wave height
T_e	energy period
$L_{p,f}$	mean-square sound pressure spectral density level
$L_{p,ddec}$	decidecade sound pressure level
$L_{p,MEC}$	marine energy converter sound pressure level
$\overline{V_f^2}$	mean-square voltage spectral density
$\overline{p_f^2}$	mean-square sound pressure spectral density
CEC	current energy converter
MEC	marine energy converter
OTEC	ocean thermal energy converter
WEC	wave energy converter
AEP	annual energy production

5 Outline of method

Measurements of underwater sound around marine energy converters (MECs) are undertaken to characterize MEC sound. This document focuses on measurements of underwater sound utilizing hydrophones, which are sensitive to fluctuations in acoustic and non-acoustic pressure. Deployment mechanisms to minimize measurement contamination by non-acoustic pressure fluctuations are given for each class of MEC, specifically current energy converters (CECs), wave energy converters (WECs), and Ocean Thermal Energy Conversion (OTEC) systems. These measurements are complemented by contextual observations of metocean conditions, sound speed profiles, and MEC operation (e.g., rated capacity, annual energy production (AEP)). The acoustic frequencies of interest for these measurements coincide with those of aquatic species, extending from a few Hz to over one hundred kHz. Two levels of characterization are described. Level A characterization describes the temporal and spatial characteristics of MEC sound. Level B characterization describes the characteristics of MEC sound at reduced temporal and spatial detail. Both levels utilize the same instrumentation, analysis, and reporting. "Level B" characterization is included within the document to provide a mechanism for reduced-effort reconnaissance surveys to be compliant with the specification. For example, a Level B characterization might be sufficient for a prototype demonstration of a MEC, whereas as Level A characterization might be more suitable for a commercial deployment. For both levels of characterization, analysis requires identifying, from all collected acoustic samples, a sufficient valid set at specified marine energy converter operational conditions and spatial positions. Measurement procedures for the three classes of MEC are summarized in Table 1.

Table 1 – Summary of measurement procedures

	WEC (7.4)		CEC (7.5)		OTEC (7.6)	
	Level A	**Level B**	**Level A**	**Level B**	**Level A**	**Level B**
Acoustic measurements						
Default low-frequency limit	10 Hz (7.3.2)					
Default high-frequency limit	100 kHz (7.3.2)					
Measurement platform	Fixed	Fixed or Drifting	Fixed or Drifting		Drifting	
Temporal extent	Sea states corresponding to 50 % of AEP or 6 months of measurements	Any sea state that results in at least 75 % of rated capacity	Currents corresponding to 0 %, 25 %, 50 %, 75 %, and 100 % of rated capacity	Currents corresponding to 100 % of rated capacity	• Rated capacity • Idle power	Rated capacity
Spatial extent	• Two in-line with dominant wave direction • One offset	One in-line	Four zones • Upstream • Downstream • Port • Starboard	Upstream *or* downstream zone	Four zones bracketing plant in ordinate directions	Any of the four zones bracketing plant in ordinate directions
Required data for each combination of temporal and spatial extent	20 valid acoustic measurement sequences (8.5.5)		10 valid acoustic measurement sequences (8.5.6)		20 valid acoustic measurement sequences (8.5.7)	
Contextual measurements						
Sound speed profile	6.3.5		6.3.5		6.3.5	
Current	6.3.4 (Grade 2)		6.3.4 (Grade 1)		6.3.4 (Grade 2)	
Wave	6.3.3 (Grade 1)		6.3.3 (Grade 2)		6.3.3 (Grade 2)	
Wind	6.3.2 (Grade 2)		6.3.2 (Grade 2)		6.3.2 (Grade 2)	
MEC	6.3.6		6.3.6		6.3.6	
Valid sequences are those sequences that do not include obvious contamination by flow-noise, self-noise, anthropogenic sources, or biological sources.						

6 Instrumentation

6.1 Sound measurement system

6.1.1 General

The term "sound measurement system" refers to the complete instrumentation system consisting of the sensitive elements (also known as the "hydrophone"), signal conditioning stages (including gain and filters), acquisition (analog to digital conversion), communication, transmission, and data storage. This term applies to systems where these components are closely integrated as a single package by a manufacturer, as well as discrete components from one or more manufacturers assembled into a system.

NOTE The signal is defined here as the time-varying voltage.

6.1.2 Frequency range

The default frequency range is 10 Hz – 100 kHz. This frequency band is selected to cover most of the frequencies that may be audible to aquatic life, with the recognition that this may be adjusted to satisfy case-specific regulatory requirements.

Conditions under which it is allowable to increase the low-frequency limit and change the high-frequency limit in the absence of case-specific regulatory requirements are described in 7.3.2.

The frequency range applies to all components of the sound measurement system (i.e., from hydrophone to recording device).

6.1.3 Sensitivity and dynamic range

The sound measurement system should have sufficient sensitivity and dynamic range to measure ambient noise exceeding typical sea-state 1 conditions up to maximum levels received by the MEC without saturating. Combined receiving voltage sensitivity and amplifier gains should be between -165 dB to -145 dB re 1 V/μPa for 16-bit systems. Combined sensitivities between -180 dB to -145 dB re 1 V/μPa should be acceptable for higher bit depths.

The non-acoustic self-noise mean-square sound pressure spectral density level should be less than 55 dB re 1 μPa^2/Hz for frequencies between 100 Hz-1 000 Hz.

To establish the non-acoustic self-noise, an air-side test of the sound measurement system should be conducted in a relatively quiet environment where the hydrophone is isolated from vibrations (e.g., wrapped in foam in a laboratory setting). The mean-square sound pressure spectral level may be calculated as for in-water acoustic measurements (8.5.2).

6.1.4 Hydrophone directionality

The hydrophone response should be omnidirectional in the horizontal plane to ±5 dB over the specified frequency range. There is not a similar requirement for vertical directionality. The sound measurement system should be assembled in such a way as to minimize additional horizontal directionality and minimize the impacts of vertical directionality.

6.1.5 Data acquisition and playback system

The data acquisition, recording, processing, and display system should be capable of accurately acquiring, recording, processing, and displaying data from the hydrophone(s) in accordance with ISO 17208-1.

The analog-to-digital conversion system should be at least 16-bit.

NOTE A higher bit depth will allow a more sensitive hydrophone to be used without saturating at maximum received levels around a MEC.

Such systems may comprise tape recorders, computer-based data acquisition systems, or hardware-specific devices (such as spectrum analyzers) or combinations of such. The data acquisition system should have an appropriate sampling rate following Nyquist requirements and appropriate dynamic range for either analog or digital systems.

6.1.6 Calibration

During acoustic measurements of marine energy converters, the complete sound measurement system should be calibrated immediately before and after the measurement session at one or more frequencies using an acoustical calibrator on the hydrophone in accordance with IEC 60565. The calibrator should, itself, be calibrated at least every 24 months.

Because hydrophones are a critical component of the measurement system, hydrophone calibration values should be provided by a calibration laboratory or by the manufacturer, and not merely be indicative or nominal values indicated by the manufacturer's design specification. The hydrophone calibration should be over the specified frequency range and conducted in accordance with IEC 60565 with the exception that the calibration should be updated every 24 months (rather than 12 months). The calibration should also be updated if the acoustical calibrator indicates a change in sensitivity of more than 5 dB.

NOTE IEC 60565 allows for multiple methods of calibration, including in-air methods for lower frequencies.

If it is impractical to test the entire sound measurement system (e.g., data acquisition system powered by a local grid that cannot be recreated in a laboratory setting), it is acceptable to provide justification and clear reasoning why the entire sound measurement system was not tested, along with an assessment of the implication for measurement accuracy.

If the data acquisition system is not integrated with the hydrophone, then proper operation should be verified in a laboratory setting at least every 24 months.

6.2 Deployment platforms for sound measurement systems

6.2.1 Fixed platforms

6.2.1.1 General

"Fixed" deployment platforms generally constrain the movement of the acoustic measurement system in response to metocean forcing, such that their average spatial position does not change in time.

The advantage of fixed platforms is their persistence at a specific location over long periods of time, which is a particularly useful attribute for acoustic measurements around wave energy converters.

The disadvantage of fixed platforms is that it is possible for relative velocity to develop between the hydrophone and surrounding water (e.g., wave orbital velocities in water that is shallow relative to the wavelength), which will produce flow-noise contamination.

It is allowable to introduce compliant elements that decouple the hydrophone element from platform vibration, including vibration transmitted through the seabed. It is also allowable to introduce compliant elements that allow the hydrophone to move in response to wave orbital motion. If compliance is introduced between the hydrophone and the fixed anchor point, then the maximum vertical and horizontal displacement relative to a neutral position shall be estimated and reported.

6.2.1.2 Establishing platform location

If the fixed platform is deployed by a surface vessel, its location on the seabed should be confirmed by an IEC 61108-4 compliant Global Navigation Satellite System (GNSS) co-located with the deployment system and the line angle should minimized during deployment.

If the fixed platform is deployed by divers, its position on the seabed should be estimated with an accuracy of at least ±10 m.

NOTE Because the minimum separation distance between a fixed platform and a MEC is 100 m (7.4.4 and 7.5.4), a positioning error of 10 m would be expected to contribute to a propagation loss uncertainty on the order of 1 dB.

6.2.2 Drifting platforms

6.2.2.1 General

"Drifting" deployment platforms are generally unconstrained in response to external forcing, including metocean forcing, buoyancy engines, and thrusters, such that their average spatial position changes in time. Drifting platforms includes systems with surface expressions (e.g., spar buoys) and fully submerged platforms (e.g., floats, autonomous underwater vehicles).

The advantage of drifting platforms is that they can be configured to minimize relative motion between the hydrophone and surrounding water, which minimizes flow-noise contamination.

The disadvantages of drifting platforms are:

a) they cannot be used to collect long-term data at a single location,
b) such platforms can still produce acoustic self-noise or contribute to flow-noise contamination,
c) their trajectory cannot be controlled, such that data collection may require a "trial and error" approach, and
d) there is a risk of entanglement with a MEC.

If a drifting platform supports external forcing capabilities (i.e., propulsion), these shall be disabled during acoustic measurement sequences to limit self-noise production.

6.2.2.2 Establishing platform location

If the drifting platform has a surface expression, it should be equipped with an IEC 61108-4 compliant Global Navigation Satellite System (GNSS).

If the drifting platform is fully submerged in operation, a combination of an acoustic positioning system and dead reckoning that yields an accuracy of at least ±3 m in the horizontal and vertical directions shall be used to track location. The details of the method used to establish position should be summarized and reported, including the type of system, operating frequency, and details sufficient confirm that use falls within manufacturer specifications.

For measurements around WECs and OTEC plants, the position shall be stored with an acquisition rate of at least 1 Hz.

For measurements around CECs, the position shall be stored with an acquisition rate of at least 5 Hz.

NOTE This difference is to account for the faster speed over ground encountered in drifting measurements around CECs.

6.2.2.3 Establishing hydrophone location

For drifting platforms with a surface expression, differential forcing on surface and subsurface elements may result in a meaningful average displacement between the hydrophone element and GNSS.

If a displacement of more than 3 m is not physically possible, then the hydrophone location may be assumed to be the same as the platform location.

If a displacement of more than 3 m is possible, then the offset between the hydrophone location and the surface expression should be estimated. Allowable methods include correction by combinations of inertial measurement units and pressure sensors, as well as electromagnetic positioning systems and acoustic positioning systems. The method used to establish hydrophone position shall be summarized and reported in sufficient detail to confirm that it is likely to produce a position accuracy of at least ±3 m.

6.2.3 Flow-noise and self-noise minimization

Fixed and drifting platforms may experience flow-noise and self-noise that masks the propagating sound produced by MECs. At present, there are neither benchmark systems nor specific procedures that can be used to quantify flow-noise and self-noise in sound measurement systems suitable for measuring sound around MECs.

Sound measurement systems that produce high-amplitude flow-noise and/or self-noise will be unable to characterize MEC sound at some frequencies, which may lead to an over-estimate of MEC sound. Consequently, it is desirable to minimize flow-noise and self-noise to the extent possible. Treatment of self-noise and flow-noise noise are discussed in 8.5.

Recommended approaches to minimize flow-noise are given in Annex C and recommended approaches to minimize self-noise are given in Annex D.

6.3 Contextual measurements

6.3.1 General

Simultaneous observations of metocean currents (winds, waves, and currents), sound speed profiles, and MEC output can provide useful context for acoustic measurements. Instrumentation and measurement specifications for metocean observation are separated into two grades:

- Grade 1 observations are quantitative descriptions of metocean conditions central to MEC operation (e.g., the wave environment for a WEC).
- Grade 2 observations are qualitative descriptions of metocean conditions that may affect MEC operation or the accuracy of acoustic measurements.

The grades are summarized by MEC type in Table 2.

The option for qualitative observations of some metocean conditions is intended to minimize the cost and complexity of acoustic characterization. These are minimum requirements; if Grade 1 observations are available, they should be reported for all types of MECs.

Table 2 – Minimum measurement grades for metocean observations by category of marine energy converter

	WEC	**CEC**	**OTEC**
Wind	Grade 2	Grade 2	Grade 2
Wave	Grade 1	Grade 2	Grade 2
Current	Grade 2	Grade 1	Grade 2

6.3.2 Winds

6.3.2.1 Grade 1

Grade 1 measurements of wind speed are optional for all MECs included in this specification.

The wind speed should be measured using an anemometer during the time period over which the acoustic measurements are performed. The minimum data collection requirements for an anemometer are:

- record a continuous time series of wind speed and wind direction;
- record data with a minimum sampling frequency of 1 Hz;
- record time-stamped data;
- record wind speeds with a maximum deviation of 1 m/s from the calibration values; and

- record winds directions within 10 degrees of the calibration values.

Any measurements collected should adhere to the following:

- the anemometer should be at an elevation of at least 0,5 m above the sea surface and the actual elevation relative to the mean sea level or other meaningful vertical reference should be reported;
- the anemometer should not be shadowed by any structure to which it is mounted; and
- the geographic position of the wind speed measurements should be at a location representative of the MEC location. That is, whether land- or ship-based, the anemometer should be unobstructed and unaffected by topographical features would affect local wind speed measurements.

The anemometer should be calibrated at least every 12 months, in accordance with IEC 61400-12-1.

The following information about the anemometer should be summarized and reported:

- the anemometer type;
- the inherent uncertainty for the anemometer given the data collection parameters and processing/reporting period;
- and details on the anemometer calibration.

6.3.2.2 Grade 2

For drifting measurements, the wind speed should be qualitatively assessed during the time period over which the acoustic measurements are performed using the Beaufort wind force scale. For fixed measurements, neither a qualitative nor a quantitative assessment of wind speed is required.

6.3.3 Waves

6.3.3.1 Grade 1

The wave measuring instrument should comply with the specifications and calibration protocols given in IEC TS 62600-100:2012 (Clause 7) and be capable of making wave measurements over the same period as the acoustic measurements.

The following information about the wave measuring instrument should be summarized and reported:

- the wave measuring instrument device type;
- the uncertainty in the wave height and direction given the data collection parameters; and
- details on the instrument calibration.

6.3.3.2 Grade 2

The sea state should be qualitatively assessed by an observer during the time period over which the acoustic measurements are performed.

6.3.4 Currents

6.3.4.1 Grade 1

The current measuring instrument should comply with the specification, calibration, and deployment protocols given in IEC TS 62600-200:2013 (Clauses 7 and 8) and be capable of making current measurements over the same period as the acoustic measurements.

The following information about the current measuring instrument should be summarized and reported:

- the current measurement device type;
- the uncertainty in the current velocity and direction given the data collection parameters; and
- details on the instrument calibration.

6.3.4.2 Grade 2

For drifting measurements, the current speed should be qualitatively assessed by an observer during the time period over which the acoustic measurements are performed. For fixed measurements, neither a qualitative nor a quantitative assessment of current speed is required.

6.3.5 Sound speed profiles

Sound speed profiles should be measured during periods representative of the environmental conditions at the site over the duration of the acoustic measurements. The sound speed can be either measured directly using a time-of-flight instrument or calculated using measurements of the depth, temperature, and salinity. Sound speed measurements should be collected in a manner that allows for a resolution of at least 1 m (i.e., the combination of sampling rate and cast speed should yield this resolution).

The instrument should have uncertainties corresponding to less than:

- 1 m/s for instruments directly measuring the sound speed;
- 1 m in depth (or 10 kPa), 0,25 °C, and 50 µS/cm (or practical salinity 0,5) if the sound speed is calculated based on measurements on the depth, temperature, and salinity.

The instrument used to obtain the profiles should be calibrated at least every 12 months. The instrument type and details of calibration should be summarized and reported.

6.3.6 Marine energy converter output

6.3.6.1 General

Marine energy converter output may be related to the magnitude and frequency of sound produced. As such, output should be measured during acoustic measurements.

6.3.6.2 Wave energy converters

WEC output should be measured as specified by IEC TS 62600-100:2012 (Clause 8). WECs that produce power outside the scope of IEC TS 62600-100 are also outside the scope of this document.

6.3.6.3 Current energy converters

CEC output should be measured as specified by IEC TS 62600-200:2013 (Clauses 7 and 8). CECs that produce power outside the scope of IEC TS 62600-200 are also outside the scope of this document.

6.3.6.4 Ocean thermal energy converters

OTEC plant output should be measured as specified by IEC TS 62600-20. OTEC plants that produce power outside the scope of IEC TS 62600-20 are also outside of the scope for this specification.

7 Measurements and measurement procedures

7.1 Metocean conditions

7.1.1 General

The minimum grade of measurement procedure required by MEC type is summarized in Table 2.

7.1.2 Winds

7.1.2.1 Grade 1

Wind speed and direction should be recorded simultaneously with acoustic measurements.

7.1.2.2 Grade 2

Wind speed should be qualitatively recorded using the Beaufort wind force scale. If changes in the qualitative wind speed or direction are observed during the measurement period this should also be recorded and the time of the change noted.

7.1.3 Waves

7.1.3.1 Grade 1

The wave measuring instrument should comply with the deployment protocols given in IEC TS 62600-100:2012 (Clause 7). Information sufficient to estimate the significant wave height (H_{m0}) and energy period (T_e) should be recorded simultaneously with acoustic measurements. Wave measurements should be simultaneous with acoustic measurements.

7.1.3.2 Grade 2

Wave conditions should be qualitatively assessed using the WMO scale for sea state (World Meteorological Organization, 2001). If changes in the sea state are observed during the measurement period this should also be recorded and the time of the change noted.

7.1.4 Currents

7.1.4.1 Grade 1

The current measuring instrument should comply with the deployment protocols given in IEC TS 62600-200. Information sufficient to estimate the current speed and direction as a function of depth should be recorded simultaneously with acoustic measurements. Current measurements should be simultaneous with acoustic measurements and may be continuous or duty-cycled.

7.1.4.2 Grade 2

Current speed should be qualitatively recorded as “quiescent”, “light”, “moderate”, or “strong”. If changes in the current speed or direction are observed during the measurement period this should also be recorded and the time of the change noted.

7.2 Potential sources of acoustic masking

7.2.1 General

The following noise sources may substantially mask MEC sound. Their time of occurrence/presence should be noted if observations are available during acoustic measurements. This information may be helpful during quality assurance review of collected acoustic data (8.5.4).

NOTE Such observations are unlikely to be available for Level A or Level B (fixed) characterizations of WECs.

7.2.2 Vessel noise

Nearby vessels have the potential to elevate noise at similar frequencies to MECs. If a vessel is in visible range during tests, the type of vessel and range from the sound measurement system(s) should be recorded, if possible.

The use of an Automatic Information System (AIS) recorder is an effective, but not required, method to obtain this information for many, but not all, types of vessels, including those beyond visible range. Military, fishing, and recreational vessels are not required to operate AIS beacons, but may produce significant sound.

7.2.3 Biological noise sources

The presence of any potentially vocal marine mammals or other sound-producing aquatic species (e.g., snapping shrimp), in the study area should be noted and the lowest level taxonomic classification recorded.

7.2.4 Precipitation

Precipitation has the potential to elevate noise at frequencies greater than 1 kHz. The qualitative aspects of the precipitation should be noted (e.g., “heavy rain”, “light shower”).

7.2.5 Air traffic

Low-elevation air traffic may contribute significantly to near-surface ambient noise. If possible, the type of aircraft and range should be recorded.

7.2.6 Physical sources

Physical processes, such as breaking waves, may elevate sound and should be noted in observations.

7.3 Underwater sound from marine energy converters

7.3.1 Levels of characterization

The objective of a Level A characterization is to quantify MEC sound across a range of temporal and spatial scales. The objective of a Level B characterization is to quantify MEC sound at a particular time and point in space. A Level A characterization can be considered as a sequence of Level B characterizations (see discussion in Clause 5).

7.3.2 Measurement frequency range

The default low-frequency limit for observations is 10 Hz. In the absence of specific regulatory guidance, this may be increased to account for the modal cut-off associated with water depth (Jensen *et al.* 2011) as:

$$f_{\text{low}} = \frac{c}{4D\left(1 - c^2 / c_s^2\right)^{1/2}}$$

where

c is the speed of sound at mid-water (in m/s),

c_s is the sound speed of the seabed, and

D is the water depth (in m).

NOTE 1 It is possible that some types of MECs may produce sound at frequencies below 10 Hz (e.g., the frequency of blade passage on a CEC). Such sound would be expected to have limited effects on marine life and would be difficult to measure in energetic environments.

The default high-frequency limit for acoustic observations should be 100 kHz. The sample rate should be at least 256 kHz for data acquisition (2,56x the high-frequency limit) to provide separation between the highest frequencies of interest (100 kHz) and the Nyquist frequency (128 kHz).

The high-frequency limit may be reduced by identifying the highest-frequency sound attributable to a MEC. Attribution of sound to a MEC is based on a comparison of the mean-square sound pressure spectral density level recorded at specified range from the MEC to a reference level.

The reference and MEC spectral density levels shall be obtained using the data collection methods described in Clause 7 and analysis procedures described in Clause 8. Observations shall be obtained under metocean conditions during which the MEC produces at least 50 % of its rated capacity.

The reference level may be derived from either:

a) An asynchronous observation at the MEC deployment site, in the absence of the MEC, under equivalent metocean, anthropogenic, and biological conditions.
b) A synchronous observation at an acoustically similar location. This location shall be no more than 2 km from the MEC, have a water depth within 10 % of the MEC deployment site, and have no material proximity difference to sources of ambient noise that are observable at the MEC site.

The high-frequency limit may be reduced to the frequency at which the MEC spectral density level never again exceeds 5 dB of the reference spectral density level, plus 10 kHz.

The high-frequency limit may be increased to frequencies known to be used by marine life (e.g., harbour porpoises using frequencies between 125 kHz and 150 kHz) if:

c) The MEC is capable, or suspected, of producing sound in a frequency range higher than the high-frequency limit, and
d) Marine life using those frequencies are or have been observed in the area.

If the high-frequency limit is either reduced or increased, the recording rate shall be 2,5x the high-frequency limit.

NOTE 2 While a reduction in the high-frequency limit may be applied to any type of MEC, it is most likely to be of use when fixed platforms are used to make acoustic measurements. Reducing the high-frequency limit may help to extend the deployment duration of fixed packages otherwise imposed by finite data storage capacity.

7.4 Wave energy converters

7.4.1 WEC characteristics

WECs may produce intermittent or continuous sound through the motion of floats, power-take off (e.g., generator, gearbox, electronics), and mooring systems. Some WEC designs may also promote wave breaking, a source of broadband sound. Environmental and ecological monitoring systems may also produce sound within the frequency range of interest.

Information about mechanisms on the WEC that could produce sound (e.g., pumps, bearings) should be recorded.

This document applies to the measurement of underwater sound produced by WECs. Measurement of air-side sound is not in scope.

7.4.2 Sound measurement system deployment

7.4.2.1 Level A

Sound measurement systems shall be secured to a fixed platform such that the pressure-sensitive element is at least 1 m above the seabed, but no more than one-half of the water depth.

7.4.2.2 Level B

Sound measurement systems shall be deployed either as for a Level A characterization or deployed from a drifting platform such that the pressure-sensitive element is at least 5 m below the sea surface.

During a drift, the deployment vessel shall stand off at least 100 m from all drifting platforms and disable all vessel systems that can radiate noise (e.g., engines, generators).

7.4.3 Temporal resolution

7.4.3.1 Level A

Measurements should be acquired over a range of sea states that account for at least 50 % of AEP (as defined by IEC TS 62600-100) or six months with a measurement duty cycle of at least 50 %, whichever is shorter.

7.4.3.2 Level B

Measurements should be acquired at a sea state during which the WEC produces at least 50 % of its rated power.

7.4.4 Spatial resolution

7.4.4.1 General

All distances are in the horizontal plane, referenced to the geometric center of the WEC.

7.4.4.2 Level A

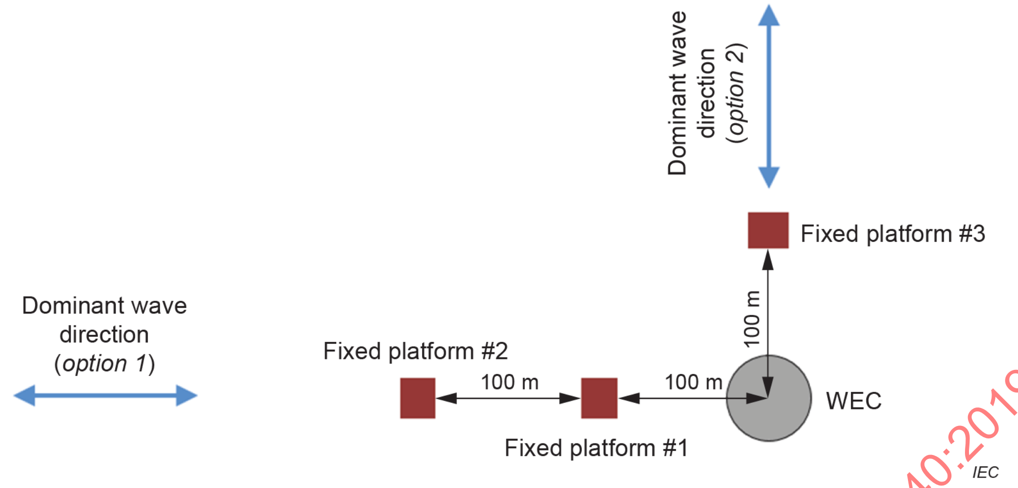
Three sound measurement systems should be deployed in any of the configurations illustrated by Figure 1. For Option 1, two sound measurement systems should be parallel to the dominant wave direction on either the up-wave or down-wave side of the WEC and one sound measurement system perpendicular to the WEC. For Option 2, two sound measurement systems should be perpendicular to the dominant wave direction and one should be parallel.

The separation distance between the closest sound measurement system and the WEC should be 100 m or four times the longest horizontal dimension of the WEC, whichever is larger.

The separation distance between the in-line sound measurement systems should be the same as the separation between the closer sound measurement system and the WEC.

The positioning accuracy of the sound measurement systems should be within 10 m of the specification on both horizontal axes (e.g., 90 m to 110 m offset with ±10 m lateral deviation).

If the specified deployment location conflicts with WEC mooring lines, it is allowable to rotate the coordinate frame around the geometric center of the WEC to the minimum extent required for safe deployment.



Fixed Platforms #1-3 required for Level A characterization.

Fixed Platform #1 required for Level B characterization.

Figure 1 – Hydrophone orientation relative to WEC

7.4.4.3 Level B

If a fixed platform is used, it should be deployed at either the location of Fixed Platform #1 or Fixed Platform #3 (Figure 1) using the same specifications as for a Level A characterization.

If a drifting platform is used, valid samples shall be georeferenced within a bounding box 25 m on edge, centered the location specified for Fixed Platform #1 in a Level A characterization.

7.4.5 Sound speed profiles

For fixed platforms, a water property or sound speed profile should be obtained within 24 h of the deployment and recovery of sound measurement systems.

For drifting platforms, a water property or sound speed profile should be obtained within 15 min of the first and last deployments of the sound measurement systems on a given day.

In both cases, sound speed profiles should be obtained from the surface to whichever is shallower: within 5 m of the seabed or to 200 m depth, and obtained as close to the location of Fixed Platform #1 as possible, within allowances for safety.

7.5 Current energy converters

7.5.1 CEC characteristics

CECs may produce sound through the motion of blades or foils (including cavitation), as well as powertrain components (e.g., generator, gearbox, electronics). Environmental and ecological monitoring systems may also produce sound within the frequency range of interest.

Information about mechanisms on the CEC that could produce sound (e.g., thrusters, blade pitch motors) should be recorded.

7.5.2 Sound measurement system deployment

Sound measurement systems may be deployed in a drifting or fixed configuration.

For drifting measurements, the pressure-sensitive element shall be at least 5 m below the water surface, but not deeper than rotor hub height. It is allowable to reduce the depth of the pressure-sensitive element if a 5 m submergence would put the sound measurement system at risk of collision with the CEC or seabed/riverbed.

During a drift, the deployment vessel shall stand off at least 100 m, in any direction, from all drifting platforms and power down all vessel systems that can radiate noise (e.g., engines, generators).

NOTE If the deployment vessel stand-off distance exceeds 300 m, it may be difficult to maintain visual contact with the drifting platform.

For fixed measurements, the pressure-sensitive element shall be at least 1 m above the seabed, but no more than one-half the water depth.

7.5.3 Temporal resolution

7.5.3.1 Level A

Measurement should be conducted during currents that result in CEC power output of 0 %, 25 %, 50 %, 75 %, and 100 % of rated capacity.

If currents at a site do not exceed one of these values for more than 10 % of a year, it is allowable to exclude this value (e.g., if currents at a site result in rated capacity being achieved only 5 % of the time, then it is not required to make an acoustic measurement at 100 % of rated capacity).

If currents do not drop below one of these values for more than 10 % of a year, it is allowable to exclude this value (e.g., if currents at a site are below cut-in speed only 5 % of the time, then it is not required to make an acoustic measurement at 0 % of rated capacity).

7.5.3.2 Level B

Measurements should be conducted during currents that result in CEC power output of 100 % of rated capacity.

If currents at a site do not exceed rated capacity for more than 10 % of the year, it is allowable to make an acoustic measurement at a current speed threshold that includes at least 75 % of AEP (as defined by IEC TS 62600-200).

7.5.4 Spatial resolution

7.5.4.1 General

All distances are in the horizontal plane, referenced to the geometric center of the CEC.

7.5.4.2 Level A

Valid samples shall be georeferenced within four zones: “upstream”, “downstream”, “port”, and “starboard”. Drifting platform(s) should be released sufficiently far upstream of the zones to allow the deployment vessel time to reach the required standoff distance and power down noise-producing systems. This is likely to require a trial-and-error approach to the location and timing of platform release.

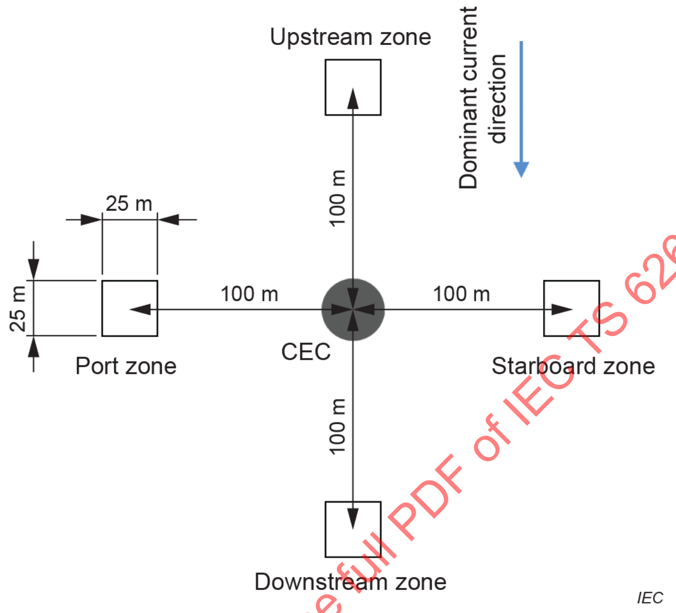
It is allowable to exclude “port” or “starboard” zones if these are in water shallower than the specified hydrophone depth in the “upstream” and “downstream” zones.

If there is a high likelihood that the acoustic measurement system could become entangled with mooring lines or other support structures, it is allowable to exclude “port” or “starboard” zones or adjust the centroid of any zone to the minimum extent required to mitigate entanglement risk.

NOTE 1 For tidal CECs, zones are referenced to the direction of the flood current, but may be populated on either ebb or flood.

Each zone measures 25 m on edge and is offset from the CEC by 100 m, or four times the longest dimension of the CEC rotor, whichever is smaller, as shown in Figure 2. For river CECs, it is allowable to calculate upstream and downstream offsets along the dominant flow streamline, rather than on the Cartesian grid shown in Figure 2.

NOTE 2 For a CEC with multiple rotors, the longest dimension of the CEC rotor is defined as the maximum linear distance across a plane intersecting the swept area of the individual rotors.



For Level A characterization, measurements shall be made in all four zones. For Level B characterization, measurements shall be made in either the upstream or downstream zone.

Figure 2 – Zones for drifting CEC measurements

7.5.4.3 Level B

Valid samples shall be georeferenced within either the “upstream” or the “downstream” zone specified for a Level A characterization.

7.5.5 Sound speed profiles

A water property or sound speed profile should be obtained within one hour of each deployment of sound measurement systems. Sound speed profiles should be obtained from the surface to whichever is shallower: within 5 m of the bottom or to 200 m depth. For Level A characterizations, sound speed profiles should be obtained as close to the “upstream” measurement zone as possible, within allowances for safety. For Level B characterizations, sound speed profiles should be obtained in the same zone as the acoustic measurements, with similar allowances for safety.

7.6 Ocean thermal energy converters

7.6.1 Overview

OTEC plants may produce sound due to machinery, fluid flow through process piping, and seawater flow through intake pipes, plant ducting and heat exchangers, and discharge pipes. OTEC plants have large components, and are likely to be sited in deeper water than other types of MECs.

Information about mechanisms on the specific OTEC plant being characterized that could produce sound should be recorded.

7.6.2 Sound measurement system deployment

Sound measurement systems shall deployed from a drifting platform such that the pressure-sensitive element is at least 5 m below the water surface, but not deeper than the cold water intake.

During a drift, the deployment vessel shall stand off at least 100 m from all drifting platforms and disable all vessel systems that can radiate noise (e.g., engines, generators).

7.6.3 Temporal resolution

7.6.3.1 General

It is recommended that acoustic measurements be conducted at sea state 2 or lower (WMO scale) to minimize the contribution of wind and waves to the measurements.

7.6.3.2 Level A

Acoustic measurements should be obtained for two states: while the plant is idle and while it is operating at 100 % of rated capacity.

7.6.3.3 Level B

Acoustic measurements should be obtained while the plant is operating at 100 % of rated capacity.

7.6.4 Spatial resolution

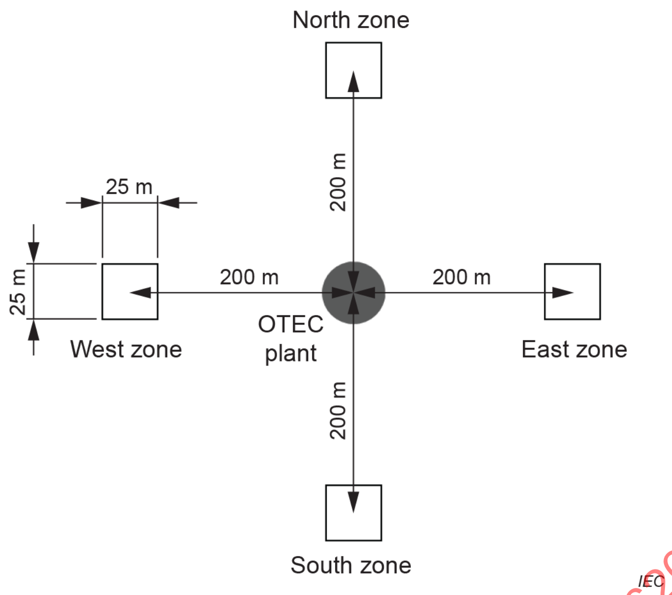
7.6.4.1 General

All distances are in the horizontal plane, referenced to the geometric center of the OTEC plant.

7.6.4.2 Level A

Valid samples shall be georeferenced within four zones corresponding to the ordinate directions referenced to magnetic north: “north”, “south”, “east”, and “west”.

Each zone measures 25 m on edge and is offset from the OTEC plant by 200 m or four times the longest dimension of the OTEC plant in the horizontal plane, as shown in Figure 3.



For Level A characterization, measurements shall be made in all four zones. For Level B characterization, measurements shall be made in any single zone.

Figure 3 – Zones for drifting OTEC measurements

7.6.4.3 Level B

Valid samples shall be georeferenced within angle single zone specified for a Level A characterization.

7.6.5 Sound speed profiles

A water property or sound speed profile should be obtained within 24 h of the deployment and recovery of acoustic measurement systems. Sound speed profiles should be obtained from the surface to whichever is shallower: the seabed, 1 000 m depth, or the depth of the cold water intake. For Level A characterizations, sound speed profiles should be obtained in the "north" zone. For Level B characterizations, sound speed profiles should be obtained in the same zone as the acoustic measurements.

8 Data analysis procedures

8.1 General

For the purposes of data analysis, an "acoustic measurement sequence" refers to either the extent of a drifting measurement that falls within the bounds of a specified "zone" or defined duration for a fixed measurement.

8.2 Metocean conditions

8.2.1 Winds

8.2.1.1 Grade 1

Wind speed and direction should be averaged over the duration of each acoustic measurement sequence.

8.2.1.2 Grade 2

For drifting platforms, a qualitative description of wind speed should be assigned to each acoustic measurement sequence. No description of wind speed is required for fixed platforms.

8.2.2 Waves

8.2.2.1 Grade 1

Significant wave height (H_{m0}) and energy period (T_e) should be assigned to each acoustic measurement sequence on the basis of linear interpolation to the temporal midpoint of the sequence from values calculated in accordance with IEC TS 62600-100.

8.2.2.2 Grade 2

A qualitative description of the sea state should be assigned to each acoustic measurement sequence.

8.2.3 Currents

8.2.3.1 Grade 1

Average current speed and direction at the turbine hub height should be assigned to each acoustic measurement sequence on the basis of linear interpolation to the temporal midpoint of the sequence from values calculated in accordance with IEC TS 62600-200.

8.2.3.2 Grade 2

For drifting platforms, a qualitative description of current speed should be assigned to each acoustic measurement sequence. No description of current speed is required for fixed platforms.

8.3 Sound speed profiles

Upcast and downcast measurements may be included in the calculation of seawater acoustic properties. If sound speed is not measured directly by a time-of-flight sensor, it should be calculated based on measurements of temperature, salinity, and depth according to Mackenzie (1981). If measured or calculated sound speed measurements are at a vertical resolution greater than 1 m, these should be linearly averaged to a vertical resolution of 1 m for reporting purposes.

For river CECs, sound speed profiles do not need to be measured or reported.

NOTE Sound speed profiles are not used within this technical specification. The collection and reporting of this information is intended to facilitate comparison between measurements of different sites and/or MECs, as well as provide context for a discussion of the results.

8.4 Marine energy converter output

8.4.1 General

MEC output, as a percentage of rated capacity, should be assigned to each acoustic measurement sequence on the basis of a linear co-temporal average of time-resolved MEC output.

8.4.2 Wave energy converters

Time-resolved WEC output should be calculated in accordance with IEC TS 62600-100.

8.4.3 Current energy converters

Time-resolved CEC output should be calculated in accordance with IEC TS 62600-200.

8.4.4 Ocean thermal energy converters

Time-resolved OTEC plant output should be calculated in accordance with IEC TS 62600-20.

8.5 Underwater sound

8.5.1 General

The outcome of signal processing and review is a minimum number of valid acoustic measurement sequences for each specified MEC operating state or metocean condition described in Clause 7.

8.5.2 Acoustic signal processing

Time series of voltages recorded by the sound measurement system should be converted to the frequency domain using a discrete Fourier transform (DFT).

NOTE 1 A description of this calculation process is available in many reference texts, for example, Thomson and Emery (2014).

The time series should be separated into 1 s windows, with each window overlapped by 50 %.

NOTE 2 To diagnose the presence of short-duration transients or harmonics at higher frequencies, it may be helpful to also process measurements at higher time resolution and coarser frequency bandwidth (e.g., 0,1 s windows, resulting in 10 Hz bandwidth).

Prior to application of the DFT algorithm, each window should be demeaned with a linear trend and weighted with a Hann taper.

The resulting double-sided spectrum should be converted to single-sided.

The resulting mean-squared voltage spectral density should be adjusted such that the total energy is equal to the variance in the time-domain window. This can be verified by the formula:

$$\overline{V^2} = \int_0^{f_{\max}} \overline{V_f^2}\, df$$

where

the left hand side of the formula is the variance in a voltage time series window,

$f_{\max}$ is the maximum resolvable frequency (Nyquist frequency), and

$\overline{V_f^2}$ is the mean-squared voltage spectral density.

The mean-square sound pressure spectral density level is related to the mean-square voltage spectral density as:

$$L_{p,f} = 10\log_{10}\left(\frac{\overline{p_f^2}}{p_o^2}\right)\text{ dB} = 10\log_{10}\left(\frac{\overline{V_f^2}}{V_o^2}\right)\text{ dB} - \left(G_f + S_f\right)$$

where

G_f is the frequency-dependent sum of amplifier gains,

S_f is the frequency-dependent receiving voltage sensitivity,

${p_o}^2$ is the reference value of 1 μPa²/Hz,

$\overline{p_f^2}$ is the mean-square sound pressure spectral density, and

${V_o}^2$ is the reference value of 1 V²/Hz.

If the frequency response of the sound measurement systems is within ± 3dB over the specified frequency range, then a single receiving voltage sensitivity may be applied to relate the mean-square sound pressure spectral density level to the mean-square voltage spectral density.

The decidecade sound pressure level is calculated as

$$L_{p,ddec} = 10\log_{10}\left[\int_{f_1}^{f_2}\left(\overline{p_f^2}\right)df \Big/ p_o^2\right] \text{dB}$$

where

f_1 and f_2 are the limits of a specified decidecade frequency band.

The marine energy converter sound pressure level is calculated as

$$L_{p,MEC} = 10\log_{10}\left[\int_{f_1}^{f_2}\left(\overline{p_f^2}\right)df \Big/ p_o^2\right] \text{dB}$$

where

f_1 and f_2 are the low-frequency limit and high-frequency limit.

8.5.3 Geo-referencing of drifting acoustic measurements

The geographic location of each sample should be geo-referenced by linear interpolation of the mid-point of the sample to the hydrophone location time-series specified in 6.2.2.

8.5.4 Global sample acceptance criteria

The following acceptance criteria apply to all types of MECs. For efficient review and acceptance, it is recommended that samples be sorted as required for specific MECs, then reviewed for MEC-specific acceptance and global acceptance.

Samples should be manually reviewed by visual inspection of the mean-square sound pressure spectral density level as a function of time (i.e., a spectrogram), visual inspection of hydrophone voltage as a function of time, and auditory review. Automatic review of samples is allowable if automatic processes yield a false positive rate (i.e., an invalid sample that is flagged as valid) of no more than 10 % relative to manual review by a trained operator.

Samples shall be excluded from further analysis if any of the following apply:

- The field calibration of the sound measurement system indicates a change in sensitivity of more than 5 dB relative to the calibration values obtained over the full frequency range (6.1.5)
- Hydrophone voltage saturates;
- A sample contains obvious non-MEC anthropogenic sound (e.g., vessel traffic, monitoring equipment);
- A sample contains obvious non-MEC biological sound (e.g., whale vocalization);
- A sample contains obvious self-noise (e.g., acoustic self-noise from hydrophone mooring, non-acoustic self-noise from the recording system);
- During a drifting platform measurement, the deployment vessel was within 100 m of the drifting platform or was operating systems that are likely to radiate noise;
- During a drifting platform measurement, hydrophone position accuracy is likely to be worse than ±6 m;

- During a drifting platform measurement, an acoustic positioning system is producing sound; or
- During a sample any of the following malfunctioned: acoustic instrumentation, instrumentation used to monitor MEC output, the MEC itself, or Grade 1 metocean instrumentation.

NOTE The determination of whether or not a sample contains "obvious" non-MEC sound from anthropogenic, biological, or self-noise is subjective. However, there is not yet a generally accepted approach to objectively discriminating between MEC and non-MEC sound.

Samples containing flow-noise may be included in analysis, but the frequencies contaminated by flow-noise shall be reported, as specified in Clause 9.

8.5.5 Considerations specific to wave energy converters

8.5.5.1 Level A

An acoustic measurement sequence is a 30 s window of continuous samples.

Acoustic measurement sequences should be binned by significant wave height (H_{m0}) in intervals of 0,5 m and energy period (T_e) in intervals of 1 s in accordance with IEC TS 62600-100.

If at least 80 % of the samples in the acoustic measurement sequence are valid, the acoustic measurement sequence is considered valid.

A minimum of 20 valid acoustic measurement sequences are required for each sea state bin. Because sea states change slowly, all samples in an acoustic measurement sequence average will have, nearly by definition, the same sea state.

Each set of continuous samples used to form an acoustic measurement sequence shall be independent (i.e., samples may only be a member of one sequence).

8.5.5.2 Level B (fixed or drifting platforms)

Acoustic measurement sequences are defined and binned as for a Level A characterization.

For drifting measurements, to be considered valid, in addition to the sample acceptance criteria given in 8.5.4, samples shall be georeferenced within the bounding box specified in 7.4.4.3.

A minimum of 20 valid acoustic measurement sequences are required that correspond to a single sea state that produces at least 50 % of WEC rated power.

8.5.5.3 Flow-noise identification

For either fixed or drifting platforms, flow-noise has potential to mask propagating WEC sound below a certain frequency. For each sea state bin, a flow-noise floor, below which flow-noise is likely to mask propagating WEC sound, should be established.

For each bin, review the median mean-square sound pressure spectral density level for valid acoustic measurement sequences. A sequence that is not contaminated by flow-noise may have a relatively "flat" (i.e., constant sound pressure) spectrum below 100 Hz. If the sound pressure increases monotonically with decreasing frequency, particularly with a slope proportional to $f^{5/3}$, this may be indicative of flow-noise contamination.

The probable flow-noise limit for the sound measurement system should be noted for each sea state bin.

NOTE 1 Flow-noise can also be identified in a spectrogram of mean-square sound pressure density level by a periodic elevation in sound pressure at a similar period to the wave energy period (T_e).

NOTE 2 For fixed hydrophones, if linear wave theory predicts peak orbital velocities greater than 0,3 m/s at hydrophone depth, then flow-noise is likely to be present at frequencies below 100 Hz, particularly if the fixed platform does not have any compliance between the anchor point and hydrophone or include a flow-shield.

NOTE 3 Because a "non-flat" spectrum below 100 Hz could also be associated with sound production by the MEC at this frequency, flow-noise will be most easily identified by comparing measurements between the MEC site and a reference location (see 7.3). If both the reference and MEC measurement have similar co-temporal mean-square sound pressure spectral density levels at low frequencies, this is likely indicative of the flow-noise threshold.

8.5.6 Considerations specific to current energy converters

8.5.6.1 General

For CECs, each sample is considered an acoustic measurement sequence.

Acoustic measurement sequences should be binned according to position (i.e., zone) and to CEC output as a percentage of rated CEC power. The bin width for the power rating is ± 10 percentage points (e.g., for the bin corresponding to 50 % of rated CEC power, samples with an instantaneous rated capacity of 40 % to 60 % of CEC rated capacity would be allowable).

To be considered valid, in addition to the sample acceptance criteria given in 8.5.4, acoustic measurement sequences shall be georeferenced within a bounding box specified in 7.5.4.

If the current measuring instrument used to collect simultaneous current conditions operated continuously at a carrier frequency within the frequency range for acoustic measurements, then the mean-square sound pressure spectral density level over this range of frequencies may be replaced by linear interpolation between the nearest unaffected frequencies. If the current measuring instrument operated intermittently, then samples contaminated by the current measuring instrument should be flagged as invalid.

For each combination of spatial bin and power rating bin, 10 valid samples are required.

8.5.6.2 Flow-noise identification

For each CEC power state, review the median mean-square sound pressure spectral density level for valid acoustic measurement sequences. If the mean-square sound pressure spectral density level increases monotonically with decreasing frequency, particularly with a slope proportional to $f^{5/3}$, this may be indicative of flow-noise contamination.

The probable flow-noise limit for the sound measurement system should be noted for each CEC power state.

NOTE If, at closest point of approach to the current measuring instrument, the speed over ground of the drifting platform differs by more than 0,3 m/s relative to the measured currents at the depth of the pressure-sensitive element, flow-noise is likely to be present at frequencies below 100 Hz.

8.5.7 Considerations specific to ocean thermal energy converters

8.5.7.1 General

An acoustic measurement sequence is as a 30 s window of continuous samples.

Acoustic measurement sequences should be binned according to position (i.e., zone) and OTEC plant status (i.e., operating at rated capacity or idle).

To be considered valid, in addition to the sample acceptance criteria given in 8.5.4, samples shall be georeferenced within a bounding box specified in 7.6.4.

If at least 80 % of the samples in the acoustic measurement sequence are valid, the acoustic measurement sequence is considered valid.

For each combination of plant status and position, a minimum of 20 valid acoustic measurement sequences are required.

Each set of continuous samples used to form an acoustic measurement sequence shall be independent (i.e., samples may only be a member of one sequence).

8.5.7.2 Flow-noise identification

If measurements are conducted at sea state zero, quiescent currents, and low winds, flow-noise should be negligible over the specified frequency range. If currents and/or winds induce platform motion, then flow-noise may be present.

The probable flow-noise limit for the sound measurement system should be noted for each OTEC plant status.

8.5.8 Aggregate statistics

For each combination of temporal bin (e.g., sea state, MEC power state) and spatial bin (i.e., zone), the following should be calculated from the samples that make up the valid acoustic measurement sequences:

- Median and the interquartile range (25th and 75th percentile) mean-square sound pressure spectral density levels. These statistics should be calculated from the mean-square sound pressure spectral densities of the samples and reported as levels, in dB, as

$$\left\langle L_{p,f} \right\rangle = 10\log_{10}\left[\left\langle \left(\overline{p^2}\right)_f \right\rangle \Big/ \left(\overline{p^2}\right)_{f,o} \right] \text{ dB}$$

  where the brackets denote a statistical operator (i.e., median, percentile).

- Median and interquartile decidecade sound pressure density levels. These statistics should be calculated from the mean-square sound pressure spectral densities of the samples and reported as levels, in dB, as

$$\left\langle L_{p,ddec} \right\rangle = 10\log_{10}\left[\left\langle \int_{f_1}^{f_2} \left(\overline{p_f^2}\right) df \right\rangle \Big/ p_o^2 \right] \text{ dB}$$

  where f_1 and f_2 are the limits of the decidecade frequency band.

- Median and interquartile MEC sound pressure levels. These statistics should be calculated from the mean-square sound pressure spectral densities of the samples and reported as levels, in dB, as

$$\left\langle L_{p,MEC} \right\rangle = 10\log_{10}\left[\left\langle \int_{f_1}^{f_2} \left(\overline{p_f^2}\right) df \right\rangle \Big/ p_o^2 \right] \text{ dB}$$

  where f_1 and f_2 are the frequency range specified in 7.3.2.

9 Information to be reported

9.1 Sound measurement system

The following should be reported:

- Narrative description of the sound measurement system, including the make and model of all components, the median water depth of the pressure sensitive element, and measures taken to minimize flow-noise and self-noise. If a flow-shield has been used to reduce flow-noise, the effect of the flow-shield on propagating sound and sound measurement system self-noise shall be quantified.
- Annotated schematic of the sound measurement system.
- Sample rate and duty cycle for sound measurement system.
- Narrative discussion of the low-frequency limit and high-frequency limit for analysis, including a justification for deviation from the standard range of 10 Hz to 100 kHz.
- Narrative description of any abnormal performance of the sound measurement system (e.g., early shutdown, data acquisition errors, mooring displacement for fixed platforms).
- Details sound measurement system sensitivity, directionality, and calibration, including a statement of compliance with IEC 60565 for calibration.
- Comparison of field calibration of the sound measurement system with the reference calibration value and a statement of compliance with IEC 60565 for the field calibration system.
- A statement verifying that non-acoustic self-noise sound pressure spectral density levels are below requirements established in 6.1.3.
- The frequency bandwidth of the mean-square sound pressure spectral density.

9.2 Marine energy conversion system

The following should be reported:

- Narrative description of the MEC, with emphasis on components of the MEC that are most likely to contribute to propagating sound.
- Details of the system used to measure the power output of the MEC during tests.

9.3 Measurement site

The following should be reported:

- Narrative description of the site.
- Narrative description of other nearby sound sources that could possibly contribute to received levels (e.g., other MECs, vessel traffic, airports, and shoreline development) and a narrative discussion of the extent to which these sounds are likely present in the measurement sequences
- Schematic showing the MEC, location of acoustic measurements (actual deployment location for fixed platforms or perimeter of bounding boxes for drifting platforms), bathymetry, and any other acoustically relevant features (e.g., location of mooring lines, buoys).
- A table describing the location, in latitude and longitude, of the MEC, acoustic measurements (actual deployment location for fixed platforms or center of the bounding boxes for drifting platforms), and any other acoustically relevant features included in the preceding schematic.

9.4 Contextual measurements

The following should be reported:

- Grade of wind, wave, and current observations and, if Grade 1, the details of the instruments and configuration used to collect these observations.
- Details of the instrument used to collect sound speed profiles.

9.5 Specific reporting for wave energy converters

9.5.1 Level A

Sound velocity profiles measured during deployment and recovery of sound measurement systems should be reported.

For each of the three spatial positions, the following figures should be produced using the valid acoustic measurement sequences.

A grid with the median MEC sound pressure level shown, by color, for each bin defined by a range of significant wave heights and energy periods. An example of this is provided in Figure 4.

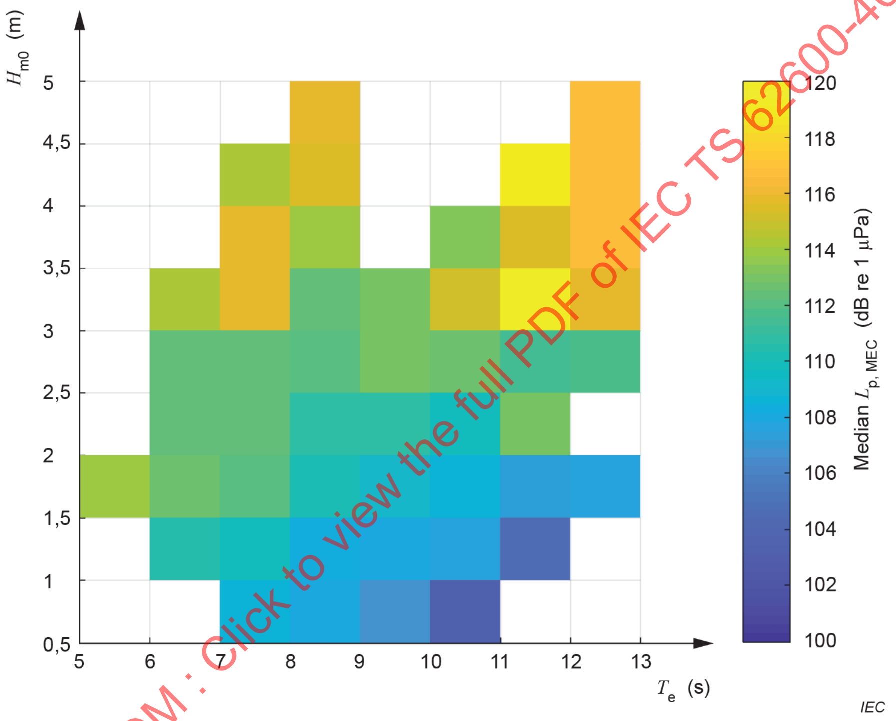
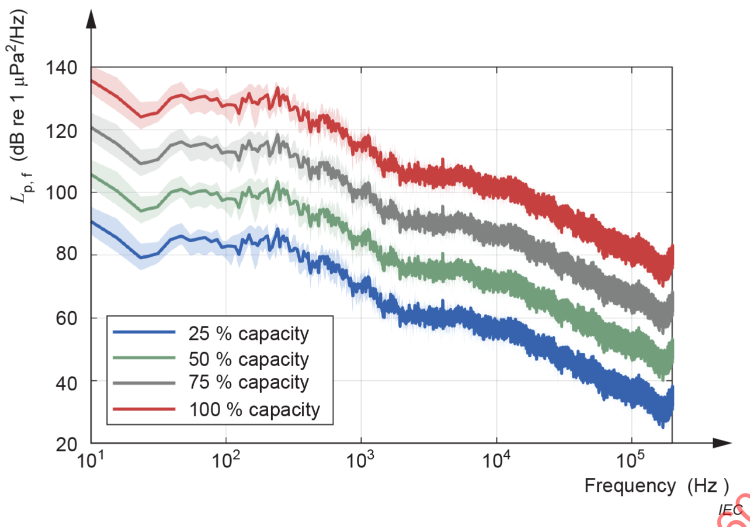


Figure 4 – Example grid of median MEC sound pressure levels as a function of significant wave height and energy period

- A grid with the flow-noise frequency limit shown, by color, for each bin defined by a range of significant wave heights and energy periods. This should mirror the format of Figure 4. A discussion should be provided of the potential effect of flow-noise on reported MEC sound pressure levels as a function of sea state.
- A grid with the median electrical power output from the WEC shown, by color, for each bin defined by a range of significant wave heights and energy periods. This should mirror the format of Figure 4.

For each of the three spatial positions, for four discrete sea states corresponding to 25 %, 50 %, 75 %, and 100 % of rated WEC capacity (within ± 10 percentage points), the following figures should be produced from the valid acoustic measurement sequences. If the deployment duration did not include any sea states corresponding to these power capacities, but otherwise satisfied the specifications for temporal observations, these figures may be presented for four other, evenly distributed power capacities:

- A plot of the median sound pressure spectral density level with the interquartile range (25^{th} – 75^{th} percentile) noted. An example of this is provided in Figure 5.



Shaded region denotes interquartile range.

Figure 5 – Example of median mean-square sound pressure spectral density level variations as a function of sea state for a single spatial position

- A plot of median decidecade sound pressure levels with the interquartile range noted. An example of this is provided in Figure 6.

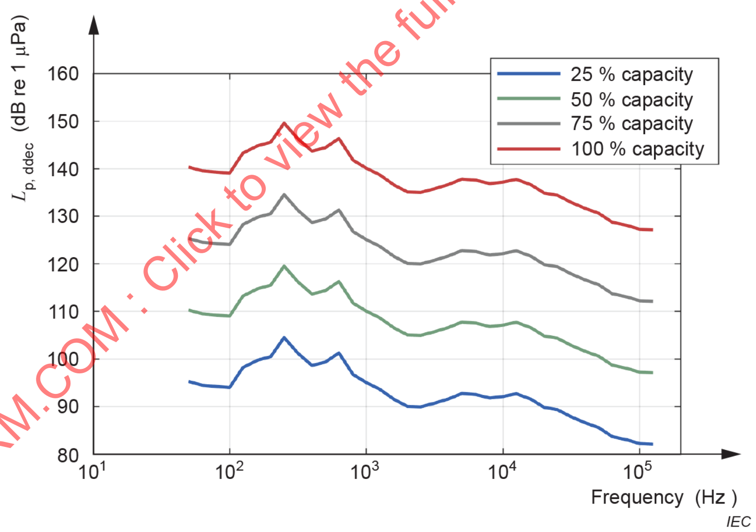


Figure 6 – Example of median decidecade sound pressure level variations as a function of sea state for a single spatial position

An annex should be included that lists, for each valid acoustic measurement sequence:

- Date and time of the sequence mid-point, with time zone indicated.
- Spatial position (e.g., “Fixed Package #1”).
- Significant wave height and associated bin.
- Energy period and associated bin.
- Median and standard deviation of WEC electrical power production during the sequence.
- Any relevant qualitative details about the sounds observed during the sequence.