



TECHNICAL SPECIFICATION



**Marine energy – Wave, tidal and other water current converters –
Part 103: Guidelines for the early stage development of wave energy converters –
Best practices and recommended procedures for the testing of pre-prototype
devices**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.140

ISBN 978-2-8322-5831-6

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

CONTENTS

| | |
|---|----|
| FOREWORD..... | 6 |
| INTRODUCTION..... | 8 |
| 1 Scope..... | 9 |
| 2 Normative references | 9 |
| 3 Terms, definitions and acronyms | 10 |
| 3.1 Terms and definitions..... | 10 |
| 3.2 Acronyms..... | 12 |
| 4 Staged development approach | 12 |
| 4.1 General..... | 12 |
| 4.2 Stage gates | 13 |
| 4.2.1 General | 13 |
| 4.2.2 Criteria | 13 |
| 4.3 Stage 1..... | 14 |
| 4.3.1 Scope..... | 14 |
| 4.3.2 Stage Gate 1 | 15 |
| 4.4 Stage 2..... | 15 |
| 4.4.1 Scope..... | 15 |
| 4.4.2 Stage Gate 2 | 16 |
| 4.5 Stage 3..... | 16 |
| 4.5.1 Scope..... | 16 |
| 4.5.2 Stage Gate 3 | 17 |
| 5 Test planning..... | 17 |
| 5.1 WEC similitudes..... | 17 |
| 5.1.1 General | 17 |
| 5.1.2 Power conversion chain (PCC) similitude..... | 17 |
| 5.2 Design statement..... | 18 |
| 5.3 Facility selection and outline plan | 19 |
| 5.3.1 General | 19 |
| 5.3.2 Stages 1 and 2 | 20 |
| 5.3.3 Stage 3..... | 21 |
| 5.4 Physical model considerations | 22 |
| 5.4.1 Stage 1..... | 22 |
| 5.4.2 Stage 2..... | 22 |
| 5.4.3 Stage 3..... | 22 |
| 6 Reporting and presentation..... | 23 |
| 6.1 Reporting of test conditions and goals | 23 |
| 6.2 Presentation of results | 23 |
| 6.2.1 General | 23 |
| 6.2.2 Wave parameters | 23 |
| 6.2.3 Response amplitude operators (RAOs) curves..... | 24 |
| 6.2.4 Scatter diagrams | 24 |
| 6.2.5 Alternative iso-variable curves..... | 25 |
| 6.3 Presentation of performance indicators | 25 |
| 6.3.1 General | 25 |
| 6.3.2 Presentation performance indicators in regular waves | 25 |
| 6.3.3 Presentation performance indicators in irregular long-crested wave..... | 26 |

| | | |
|--------|---|----|
| 6.3.4 | Presentation of performance indicators in irregular short-crested waves | 27 |
| 7 | Testing environment characterisation | 27 |
| 7.1 | General..... | 27 |
| 7.2 | Wave tank characterisation (Stages 1 and 2) | 27 |
| 7.3 | Trial site characterisation (Stage 3) | 29 |
| 7.4 | Wave characterisation..... | 29 |
| 7.4.1 | General | 29 |
| 7.4.2 | Laboratory regular waves | 29 |
| 7.4.3 | Laboratory irregular long-crested waves | 29 |
| 7.4.4 | Laboratory irregular short-crested waves | 29 |
| 7.4.5 | Sea trials | 29 |
| 8 | Data acquisition..... | 30 |
| 8.1 | Signal conditioning..... | 30 |
| 8.2 | Sample rate | 31 |
| 8.3 | Analogue to digital conversion and DAQ system | 31 |
| 8.4 | Frequency response | 31 |
| 8.5 | Data synchronisation | 31 |
| 8.6 | Data recording | 32 |
| 8.7 | Recording of supplementary test data | 32 |
| 8.8 | Calibration factors..... | 32 |
| 8.9 | Instrument response functions | 32 |
| 8.10 | Health monitoring and verification of signals | 32 |
| 8.11 | Special data acquisition requirements for Stage 3 sea trials..... | 33 |
| 9 | Power performance | 33 |
| 9.1 | Testing goals | 33 |
| 9.2 | WEC and mooring similitude | 33 |
| 9.3 | Power conversion chain similitude | 34 |
| 9.3.1 | General | 34 |
| 9.3.2 | Stage 1..... | 35 |
| 9.3.3 | Stage 2..... | 35 |
| 9.3.4 | Stage 3..... | 35 |
| 9.4 | Signal measurement | 36 |
| 9.5 | Calibration and setup | 36 |
| 9.6 | Wave parameters..... | 37 |
| 9.6.1 | Stage 1 and 2 | 37 |
| 9.6.2 | Stage 3..... | 38 |
| 9.7 | Performance indicators | 38 |
| 10 | Kinematics and dynamics in operational environments | 38 |
| 10.1 | Testing goals | 38 |
| 10.2 | Testing similitude..... | 39 |
| 10.3 | Signal measurement | 40 |
| 10.4 | Calibration and setup | 42 |
| 10.5 | Wave parameters..... | 43 |
| 10.5.1 | Stages 1 and 2 | 43 |
| 10.5.2 | Stage 3..... | 44 |
| 10.6 | Performance indicators | 44 |
| 11 | Kinematics and dynamics in survival environments..... | 45 |
| 11.1 | Testing goals | 45 |

| | | |
|--------------|---|----|
| 11.2 | Testing similitude | 45 |
| 11.3 | Signal measurements | 46 |
| 11.4 | Calibration and setup | 46 |
| 11.5 | Wave parameters..... | 47 |
| 11.5.1 | Stage 1..... | 47 |
| 11.5.2 | Stage 2..... | 47 |
| 11.5.3 | Stage 3..... | 48 |
| 11.6 | Performance indicators | 48 |
| Annex A | (informative) Stage Gates | 50 |
| A.1 | Overview..... | 50 |
| A.2 | Design statements | 50 |
| A.3 | Stage Gate criteria..... | 50 |
| A.4 | Uncertainty factors..... | 51 |
| A.5 | Third party review | 52 |
| Annex B | (informative) Example test plan..... | 53 |
| Annex C | (informative) Physical modelling guidance | 54 |
| C.1 | Similitude..... | 54 |
| C.1.1 | General | 54 |
| C.1.2 | Geometric similitude | 54 |
| C.1.3 | Structural similitude | 54 |
| C.1.4 | Hydrodynamic similitude..... | 54 |
| C.2 | Model instrumentation and data acquisition..... | 56 |
| C.2.1 | General | 56 |
| C.2.2 | Water surface elevation | 56 |
| C.2.3 | PTO..... | 56 |
| C.2.4 | Device and mooring loads | 56 |
| C.3 | Recommendations on calibrations..... | 57 |
| Annex D | (informative) Uncertainty | 58 |
| Bibliography | | 60 |
| Figure 1 | – Staged development approach | 13 |
| Table 1 | – Presentation of performance indicators (regular waves) | 26 |
| Table 2 | – Presentation of performance indicators (irregular long-crested waves) | 26 |
| Table 3 | – Presentation of performance indicators (irregular short-crested waves)..... | 27 |
| Table 4 | – Environmental measurements | 28 |
| Table 5 | – Environmental performance indicators..... | 30 |
| Table 6 | – Power performance testing similitude | 34 |
| Table 7 | – Power conversion chain (PCC) representation..... | 34 |
| Table 8 | – Power performance signal measurements | 36 |
| Table 9 | – Power performance calibrations | 37 |
| Table 10 | – Power performance wave parameters..... | 37 |
| Table 11 | – Kinematics and dynamics similitude requirements (operational environments)..... | 40 |
| Table 12 | – Kinematic signal measurements (operational environments)..... | 41 |
| Table 13 | – Dynamic signal measurements (operational environments)..... | 42 |

| | |
|---|----|
| Table 14 – Calibration for kinematic and dynamic testing (operational environments) | 43 |
| Table 15 – Wave parameters for kinematics and dynamics testing (operational conditions) | 44 |
| Table 16 – Kinematics and dynamics similitude requirements (survival environments) | 46 |
| Table C.1 – Scale laws | 55 |
| Table C.2 – Sensor calibrations | 57 |
| Table D.1 – Scale example | 59 |

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 103: Guidelines for the early stage development of wave energy converters – Best practices and recommended procedures for the testing of pre-prototype devices

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) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

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

IEC TS 62600-103, 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 specification is based on the following documents:

| | |
|---------------|------------------|
| Enquiry draft | Report on voting |
| 114/233/DTS | 114/259A/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.

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

Developing wave energy converters (WECs) will always be a demanding engineering process. It is important, therefore, to follow a design path that will minimise the risks encountered along a route of increasing technical complexity and fiscal commitment. This Technical Specification (TS) presents a guide that addresses these issues, the approach being based on a proven methodology adapted from other technology areas, especially NASA and similar heavy maritime engineering industries.

The scope of the work is defined in Clause 1. Normative references and definitions of important terms are introduced in Clauses 2 and 3 respectively. The core of the document then follows a twin-track approach, relying on:

- a) a structured or staged development approach outlined in Clause 4, and
- b) a set of model specific and goal orientated Clauses 9 to 11 ensuring that targets are clearly defined and attained with confidence. Testing specific requirements such as test planning (Clause 5), reporting and presentation (Clause 6), characterisation of the surrounding wave environment (Clause 7), and data acquisition (Clause 8) are also included.

The structured development schedule makes use of the ability to accurately scale WECs such that sub-prototype size physical models can be used to investigate the relevant device parameters and design variables at an appropriate dimension and associated budget.

The parallel development of mathematical models describing a WEC's behaviour and performance is encouraged, but the procedure is not included in the document.

This document is quite exacting in terms of both the approach and requirements for the development of WECs since it takes a professional approach to the process. Following these guidelines will not guarantee success, but not following them will be a recipe for lost time and opportunities.

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

Part 103: Guidelines for the early stage development of wave energy converters – Best practices and recommended procedures for the testing of pre-prototype devices

1 Scope

This part of IEC TS 62600 is concerned with the sub-prototype scale development of WECs. It includes the wave tank test programmes, where wave conditions are controlled so they can be scheduled, and the first large-scale sea trials, where sea states occur naturally and the programmes are adjusted and flexible to accommodate the conditions. A full-scale prototype test schedule is not covered in this document. Bench tests of PTO (power take-off) equipment are also not covered in this document.

This document describes the minimum test programmes that form the basis of a structured technology development schedule. For each testing campaign, the prerequisites, goals and minimum test plans are specified. This document addresses:

- Planning an experimental programme, including a design statement, technical drawings, facility selection, site data and other inputs as specified in Clause 5.
- Device characterisation, including the physical device model, PTO components and mooring arrangements where appropriate.
- Environment characterisation, concerning either the tank testing facility or the sea deployment site, depending on the stage of development.
- Specification of specific test goals, including power conversion performance, device motions, device loads and device survival.

Guidance on the measurement sensors and data acquisition packages is included but not dictated. Providing that the specified parameters and tolerances are adhered to, selection of the components and instrumentation can be at the device developer's discretion.

An important element of the test protocol is to define the limitations and accuracy of the raw data and, more specifically, the results and conclusion drawn from the trials. A methodology addressing these limitations is presented with each goal so the plan always produces defensible results of defined uncertainty.

This document intends to serve a wide audience of wave energy stakeholders, including device developers and their technical advisors; government agencies and funding councils; test centres and certification bodies; private investors; and environmental regulators and NGOs.

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

IEC TS 62600-2, *Marine energy – Wave, tidal and other water current converters – Part 2: Design requirements for marine energy systems*

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 62600-101, *Marine energy – Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterization*