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B-08

**MARINE SOLID-STATE HYDROGEN
STORAGE SYSTEM**

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Foreword:

China Classification Society (hereinafter referred to as CCS) Product Inspection and Testing Guideline (hereinafter referred to as this Guideline) contains the technical requirements, inspection and testing criteria related to classification and statutory survey of marine products to be applied for CCS approval/inspection.

This Guideline frees the users to adopt other test methods and requirements which are equivalent to or are stricter than this Guideline.

This Guideline is published and updated by CCS, and is released at <http://www.ccs.org.cn>. Your comments or suggestions are welcomed and may be sent to our email addressed service@ccs.org.cn

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CONTENTS

1 Application.....	错误!未定义书签。
2 Normative references.....	错误!未定义书签。
3 Terms and definitions.....	错误!未定义书签。
4 Plans and documents.....	错误!未定义书签。
5 Technical requirements	错误!未定义书签。
6 Materials and components	错误!未定义书签。
7 Type test.....	错误!未定义书签。 1
8 Unit/batch inspection	错误!未定义书签。 4

MARINE SOLID-STATE HYDROGEN STORAGE SYSTEM

1 Application

These Guidelines apply to marine solid-state hydrogen storage systems adopting the metal hydride hydrogen storage method. A marine solid-state hydrogen storage system (hereinafter referred to as the "hydrogen storage system") means an integrated and complete hydrogen storage system, comprising hydrogen storage vessels, pressure relief devices (PRD), stop valves, other accessories and internal components.

2 Normative references

- 2.1 CCS Rules for Classification of Sea-Going Steel Ships (current and valid version)
- 2.2 CCS Rules for Construction of Inland River Steel Ships (current and valid version)
- 2.3 MSA Interim Technical and Inspection Rules for Hydrogen Fuel Cell Powered Ships (2022)
- 2.4 CCS Guidelines for Marine Application of Fuel Cell Power Generation Devices (2022)
- 2.5 CCS Guidelines for Type Approval Test of Electrical and Electronic Products (2015) (including IACS UR E10 Rev.8)
- 2.6 ISO 14687:2019 Hydrogen fuel quality — Product specification
- 2.7 ISO 16111:2018 Mobile gas storage equipment — Hydrogen absorption in reversible metal hydrides
- 2.8 ISO 16852:2016 Flame arresters — Performance requirements, test methods and limits of use
- 2.9 GB/T 3634.2-2011 Hydrogen — Part 2: Pure hydrogen, high-purity hydrogen and ultra-high-purity hydrogen
- 2.10 TSG 21 Safety Technology Supervision Regulation on Stationary Pressure Vessels

3 Terms and definitions

- 3.1 For the definitions of terms such as product inspection, approval, type test, sampling, and unit/batch inspection, refer to Clause 3.1.2, Chapter 3, Part 1 of CCS Rules for Classification of Sea-Going Steel Ships.
- 3.2 Batch means products of the same specification, continuously manufactured by the same manufacturer on the same production line using the same production process.
- 3.3 Solid-state hydrogen storage means a hydrogen storage method in which hydrogen is chemically reacted with or physically adsorbed by solid materials.
- 3.4 Metal hydride means a solid material formed by the combination of metals or alloys with hydrogen, which is capable of absorbing and releasing hydrogen.
- 3.5 Hydrogen storage vessel means a containment structure of any shape (cylindrical, prismatic, cubic, etc.) designed to contain hydrogen, metal hydrides and other internal components of the

hydrogen storage system. Note: It may take the form of a cylinder, pressure vessel or other pressure-resistant vessel types.

3.6 Pressure relief device (PRD) means a safety device capable of relieving pressure to prevent rupture. A PRD may be pressure-actuated, which is triggered and activated at a specific pressure, or a combined pressure-and heat-actuated type.

3.7 Pressure relief valve means a resettable pressure relief device.

3.8 Rated capacity means the maximum hydrogen discharge capacity of a metal hydride hydrogen storage device under the technical conditions specified by the manufacturer.

3.9 Maximum delta pressure (MDP) means the maximum equilibrium gas pressure (gauge pressure) at the maximum operating temperature after the metal hydride hydrogen storage device has absorbed hydrogen to its rated capacity. The MDP is determined based on the temperature-pressure characteristics of the metal hydride at the maximum operating temperature. Under no circumstances shall the stress level at the MDP exceed 80% of the yield strength of the hydrogen storage vessel. The MDP shall not exceed 25 MPa; if it exceeds 25 MPa, a technical evaluation shall be conducted and approved by CCS.

3.10 Rated charging pressure (RCP) means the maximum pressure for filling a metal hydride hydrogen storage device. Note: The RCP is generally not equal to the equilibrium steady-state pressure of the hydrogen-absorbing alloy. The RCP is determined based on temperature-pressure characteristics to prevent the pressure generated during filling from causing the wall stress of the hydrogen storage vessel to exceed the design stress limit.

3.11 Stress level at maximum delta pressure (MDP) means the stress level determined based on the compression and expansion characteristics of the hydrogen storage alloy, the MDP inside the metal hydride hydrogen storage device, and other applicable mechanical load factors.

4 Plans and documents

4.1 Plans and documents to be submitted for review

4.1.1 The following plans and documents shall be submitted to CCS for approval:

(1) Hydrogen Storage System

- ① System flow diagram;
- ② Product technical specifications and main performance data sheet;
- ③ Detailed plans and physical/chemical property lists of the piping system, including pressure relief piping and vent piping;
- ④ Technical documents for branch pipes, return pipes, elbows, expansion joints, bellows and similar components, including strength calculation sheets;
- ⑤ Plans and descriptions of flanges, valves and other devices;
- ⑥ Relevant process documents for the piping system, including but not limited to welding

procedures and non-destructive testing specifications;

- ⑦ Technical documents for piping pressure tests (strength test and tightness test);
- ⑧ Layout plans and diagrams of monitoring devices and alarm systems, including the layout of monitoring probes, sensors, alarm devices and alarm points, as well as alarm and control set values;
- ⑨ Schematic diagrams, component lists, software function block diagrams, alarm type lists and safety action lists of control equipment (including control, alarm and safety systems);
- ⑩ Performance test outline of the hydrogen storage system, including functional verification of valves, accessories and operation-related equipment;
- ⑪ External piping connection diagram;
- ⑫ Flow-pressure diagram of the hydrogen storage system during hydrogen discharge.

(2) Hydrogen Storage Vessel

- ① Main product performance data sheet;
- ② General assembly drawing and plans of main components;
- ③ Strength calculation sheet and pressure relief device calculation sheet;
- ④ Physical/chemical property list of materials for main pressure-bearing components;
- ⑤ Description of the characteristics of hydrogen storage materials;
- ⑥ Stress analysis report of the hydrogen storage vessel (if applicable).

Note: The actual names of the plans/documents may differ from the above, but shall fully reflect the required content.

4.1.2 The following plans and documents shall be submitted to CCS for record:

- (1) Full-life performance description of the hydrogen storage system;
- (2) Failure Mode and Effects Analysis (FMEA) report of the hydrogen storage system;
- (3) Piping stress analysis report of the hydrogen storage system;
- (4) System specification or operation manual;
- (5) Nameplate drawing;
- (6) Necessary list of auxiliary equipment.

4.1.3 For the unit/batch inspection of the hydrogen storage system, the following additional plans and documents shall be submitted to CCS for review:

- (1) Schematic diagrams, component lists, software function block diagrams, alarm point lists and safety action lists of control equipment (including control, alarm and safety systems);
- (2) Explanation of consistency between the submitted plans and the approved plans;
- (3) Explanation of consistency between the submitted plans and the ship-approved plans;
- (4) Ship-approved plans and review comments.

4.2 Additional documents to be submitted for the approval of hydrogen storage vessels

- (1) Technical characteristics of the product;
- (2) Manufacturing processes and technical documents related to the product, including process flow charts;
- (3) Type test outline;
- (4) List of suppliers of raw materials and main components of the product;
- (5) Necessary quality assurance system documents;
- (6) List of main production equipment and inspection & test equipment for the product;
- (7) Other valid documents, reports and certificates demonstrating the manufacturer's production capacity and quality level within the scope of approval;
- (8) Enterprise registration certificate, business license, qualification certificate and/or production license (if applicable);
- (9) The quality certificate for marine products subject to CCS product inspection (including information on applicable standards, product performance, quality assurance and liabilities) shall be written in the language specified by the purchaser; for ships sailing internationally, it shall include at least English.

5 Technical requirements

5.1 Working conditions

The hydrogen storage system shall be capable of normal operation under the working conditions specified in Clause 2, Chapter 1, Part 3 of CCS Rules for Classification of Sea-Going Steel Ships. If it is only used for inland river ships, it shall meet the normal operation requirements under the working conditions specified in Clause 1, Chapter 1, Part 2 of CCS Rules for Construction of Inland River Steel Ships.

5.2 System design

5.2.1 The risk control in the design of the hydrogen storage system shall comply with the requirements of Clause 7.2 of GB/T 29729-2022.

5.2.2 The hydrogen storage system shall adopt a modular structure to facilitate assembly, inspection and maintenance. Layout measures such as component spacing shall be considered to

ensure uniform and sufficient heat exchange; the heat generated by the operation of other equipment shall be rationally utilized.

5.2.3 The hydrogen storage system shall be equipped with safety accessories, including but not limited to pressure relief devices and stop valves, complying with the requirements of GB/T 29729-2022 or ISO 16111.

5.2.4 The hydrogen storage system shall be rationally equipped with temperature and pressure monitoring devices.

5.2.5 The hydrogen storage system shall be provided with hydrogen discharge pipes, purge ports and flame arresters. Flame arresters shall be installed on the pipelines connected to hydrogen-using equipment with open flames and on the centralized hydrogen vent pipes, complying with the requirements of ISO 16852.

5.2.6 For hydrogen storage systems using an active cooling system to control and/or influence the system temperature, no liquid leakage between the hydrogen storage vessel and the cooling system shall be allowed. The cooling system shall be in operation during the hydrogen cycle test and strain measurement test. If the cooling medium may react with the metal hydride, a proper risk assessment shall be conducted prior to the use of such cooling medium.

5.2.7 Effective measures shall be taken to prevent particulates from interfering with the function of valves or pressure relief devices, and to ensure that the metal hydride hydrogen storage device can meet the requirements of the combustion test, hydrogen cycle test and strain measurement test.

5.2.8 Hydrogen-related piping systems in the hydrogen storage system shall comply with the requirements of CCS Class I piping systems and shall be designed with thermal and cold compensation structures.

5.2.9 The quality of hydrogen released by the hydrogen storage system shall be compatible with downstream applications.

5.3 Hydrogen storage vessel

5.3.1 Layout

5.3.1.1 Hydrogen storage vessels shall be arranged to minimize the probability of damage in the event of collision or grounding, and shall be placed as close to the ship's centerline as practicable.

5.3.1.2 When hydrogen storage vessels are connected to the ship system, their supporting and fixing devices shall be designed based on the maximum expected static and dynamic inclination angles and the maximum expected acceleration values to prevent displacement of the hydrogen storage vessels.

5.3.1.3 Hydrogen storage vessels shall be protected against mechanical damage.

5.3.1.4 The relevant connecting piping of hydrogen storage vessels shall be provided with sufficient flexible compensation

5.3.2 Design

5.3.2.1 General requirements

The design of hydrogen storage vessels shall comply with the requirements of Clause 5.3 of ISO 16111. The internal volume of a hydrogen storage vessel shall generally not exceed 150 L, and the MDP shall not exceed 25 MPa. If the internal volume of a hydrogen storage vessel exceeds 150 L, a technical evaluation shall be conducted and approved by CCS.

5.3.2.2 Design strength

The design of hydrogen storage vessels shall take into account the stress level at 1.25 times the MDP. The possible impacts of various components on the stress level at the MDP include but are not limited to:

- (1) $1.25 \times$ maximum delta pressure (MDP);
- (2) Thermal stress, including stress caused by differential thermal expansion and contraction;
- (3) Weight of internal structures in any possible direction within the metal hydride hydrogen storage vessel;
- (4) Impact and vibration loads;
- (5) Maximum stress caused by the expansion of the hydrogen-absorbing alloy;
- (6) Other mechanical loads.

5.3.2.3 Other requirements

- (1) Hydrogen storage vessels shall be designed to prevent local accumulation of solid fillers during service;
- (2) The ports of a single hydrogen storage vessel or a vessel bank shall be equipped with filters whose filtration accuracy matches the particle size of the solid hydrogen storage material. The possible pulverization of the solid hydrogen storage material during service shall also be taken into account;
- (3) Hydrogen storage vessels that assist hydrogen absorption and desorption through thermal effects shall be designed as heat exchanger structures according to the hydrogen storage capacity and the thermal effect level of the solid hydrogen storage material.

5.3.3 Performance and safety requirements

5.3.3.1 Materials in contact with fuel in hydrogen storage vessels shall be compatible with hydrogen, and the impact of hydrogen embrittlement on service life shall be considered.

5.3.3.2 Devices capable of limiting the leakage rate in the event of accidental disconnection or rupture of hydrogen storage vessel connections shall be provided.

5.3.3.3 The design of hydrogen storage vessels and hydrogen supply piping shall ensure that safety actions taken after leakage will not cause unacceptable consequences.

5.3.3.4 The design and construction of hydrogen storage vessels shall prevent the leakage of hydrogen or metal hydride during the normal operation of the system.

5.3.3.5 The minimum quality of hydrogen to be filled into hydrogen storage vessels shall be specified by the manufacturer in accordance with the requirements of ISO 14687. If hydrogen quality is a key factor affecting the performance of hydrogen storage vessels, the manufacturer may consider marking the hydrogen quality requirements on the product nameplate.

5.4 Process control and safety system

The control, alarm and safety systems of the hydrogen storage system shall comply with the relevant requirements of Chapter 2, Part 7 of CCS Rules for Classification of Sea-Going Steel Ships.

5.4.1 Structure

5.4.1.1 Appropriate instrumentation shall be provided to display the key parameters of the hydrogen storage system both locally and remotely to ensure the safe management of all fuel equipment and filling operations.

5.4.1.2 A pressure indicator for local reading shall be provided to indicate the pressure between the ship's piping stop valve and the shore connection hose.

5.4.1.3 At least one locally displayed pressure gauge shall be installed on each hydrogen main pipe.

5.4.1.4 A pressure gauge shall be installed locally on each hydrogen storage vessel, with the allowable maximum and minimum pressures of the hydrogen storage vessel clearly marked on it. Pressure display shall also be provided at the remote control position (such as the wheelhouse, engine room control room or ship safety center). In addition, high and low pressure alarms shall be set in manned spaces and activated when the design maximum/minimum pressure is reached.

5.4.1.5 Hydrogen storage vessels shall be equipped with pressure sensors to cut off the fuel output in a timely manner when the internal pressure of the vessel is lower than the minimum pressure required for safety.

5.4.2 Functional and safety requirements

5.4.2.1 Abnormal pressure/temperature of relevant equipment of the solid-state hydrogen storage system shall be monitored, and audible and visual alarms shall be activated when the limit values are exceeded;

5.4.2.2 Gas leakage of the solid-state hydrogen storage system shall be monitored, and audible and visual alarms shall be activated when the limit values are exceeded;

5.4.2.3 For electrical equipment involved in the hydrogen storage system, if explosion-proof equipment of a qualified type is required according to the hazardous area classification, its explosion-proof category shall not be lower than Ex d IIC and the temperature class shall not be lower than T1.

6 Materials and components

The raw materials and components of the product shall be controlled in accordance with the relevant requirements of the current CCS Rules. Solid hydrogen storage materials with the

characteristics of hydrogen charging, storage and discharge at low pressure and normal temperature shall be preferred to minimize the energy consumption of the system during the hydrogen storage and discharge processes.

7 Type test

7.1 Selection of typical samples

7.1.1 Hydrogen storage vessels shall undergo type test for each distinct type. A vessel shall be regarded as a different type if any of the following conditions is different:

- (1) Production process flow;
- (2) Material grade;
- (3) Heat treatment process;
- (4) Bottom structure form, or the ratio of bottom thickness to cylinder diameter;
- (5) Vessel length increased by more than 50% (vessels with a length/diameter ratio less than 3 shall not be used as a reference for any vessel with a length/diameter ratio greater than 3);
- (6) Outer diameter or minimum guaranteed thickness of the hydrogen storage vessel;
- (7) Hydrostatic test pressure (a mere reduction of the hydrostatic test pressure based on an existing design shall not be regarded as a new design);
- (8) Reduction of the minimum guaranteed yield strength and/or the minimum guaranteed tensile strength.

7.1.2 The hydrogen storage vessels selected as samples for the type test shall undergo raw material acceptance, key manufacturing processes, inspection & test, and relevant mark transfer under the on-site supervision of a CCS surveyor, and the results shall meet the requirements of CCS Rules for Classification of Sea-Going Steel Ships and the approved plans.

7.2 Type test items and requirements

7.2.1 Test items and requirements for the type test of hydrogen storage vessels

Type Approval Test Items for Hydrogen Storage Vessel **Table 7.2.1**

No.	Test Item	Technical Requirements and Test Method
1	Combustion Test	ISO 16111:6.2.2
2	Drop or Impact Test	ISO 16111:6.2.4
3	Leakage Test	ISO 16111:6.2.5
4	Hydrogen Cycle and Strain Measurement Test	ISO 16111:6.2.6
5	Stop Valve Impact Test	ISO 16111:6.2.7
6	Temperature Cycle Test	ISO 16111:6.2.8
7	Maximum Delta Pressure Test	ISO 16111:6.3.3
8	Burst Test	ISO 16111:6.3.2

7.2.2 Test Items and Requirements for Hydrogen Storage System Type Approval Test

Type Approval Test Items for Hydrogen Storage System **Table 7.2.2**

No.	Test Item	Technical Requirements and Test Method
1	Visual and Structural Inspection	7.2.2.1
2	Air Tightness Test	7.2.2.2
3	Overpressure Safety Performance Test	7.2.2.3
4	Hydrogen Discharge Performance Test	7.2.2.4
5	Hydrogen Charging Performance Test	7.2.2.5

7.2.2.1 Visual and Structural Inspection

During the system visual and structural inspection, the system appearance, marking, interfaces and structure shall be inspected and meet the following requirements:

- (1) The outer surface shall be clean without mechanical damage, and the interface contacts shall be free of rust; the surfaces in contact with hydrogen shall be free of burrs, welding slag, rust and dirt, etc.;
- (2) The product nameplate shall be legible;
- (3) Hydrogen charging/discharging interfaces, heat exchange medium interfaces, etc. shall be clearly marked.

7.2.2.2 Air Tightness Test

The air tightness test of the system shall be conducted in accordance with the requirements for air tightness test of pressure vessels in TSG 21.

7.2.2.3 Overpressure Safety Performance Test

Raise the hydrogen pressure of the system above the actuation pressure of the pressure relief device provided by the manufacturer, and check whether the system pressure relief device operates normally.

7.2.2.4 Hydrogen Discharge Performance Test

(1) Test Requirements

No less than 5 hydrogen storage vessels of the same specification and their attached devices in each batch of the system shall be selected for the test; the test shall be repeated no less than twice under the same working conditions, and the average value shall be taken.

(2) Test Procedures

- ① Fix the hydrogen storage vessel to be tested and its attached devices on the test bench, connect the gas circuit, conduct air tightness inspection to ensure no hydrogen leakage in the test gas circuit, and install test thermocouples;
- ② Set the instrument flow control value according to the rated hydrogen discharge rate of the tested equipment;
- ③ Turn on the test instrument, open the stop valve of the hydrogen storage vessel, measure and record the hydrogen discharge rate, hydrogen discharge capacity, hydrogen pressure

and vessel surface temperature in real time; the hydrogen storage pressure and capacity of the system shall comply with the main performance specification sheet provided by the manufacturer;

- ④ Weigh the tested hydrogen storage vessel and calculate the hydrogen storage density based on the test values of its hydrogen storage capacity and weight;
- ⑤ Determine the purity of hydrogen discharged in accordance with the test method of GB/T 3634.2, which shall comply with the main performance specification sheet provided by the manufacturer;
- ⑥ Measure and record the hydrogen discharge rate, hydrogen discharge capacity, hydrogen pressure and vessel surface temperature in real time; the negative deviation between the measured value of hydrogen discharge at the nominal rated hydrogen storage capacity and the theoretical value shall not be greater than 5%.

7.2.2.5 Hydrogen Charging Performance Test

(1) Test Requirements

No less than 5 hydrogen storage vessels of the same specification and their attached devices in each batch of the system shall be selected for the test; the test shall be repeated no less than twice under the same working conditions, and the average value shall be taken.

(2) Test Procedures

- ① Fix the hydrogen storage vessel to be tested and its attached devices on the test bench, connect the gas circuit, take corresponding measures to ensure no other impurity gas remains in the hydrogen storage vessel, conduct air tightness inspection to ensure no hydrogen leakage in the test gas circuit, and install test thermocouples;
- ② Determine the purity of hydrogen to be charged in accordance with the test method of GB/T 3634.2, which shall comply with the manufacturer's specifications;
- ③ Set the hydrogen charging pressure control value according to the rated hydrogen charging pressure of the tested equipment, which shall comply with the manufacturer's specifications;
- ④ Turn on the test instrument, open the stop valve of the hydrogen storage vessel, measure and record the hydrogen charging time, hydrogen charging capacity and hydrogen pressure at the same time;
- ⑤ Fill the hydrogen storage vessel to its rated capacity, calculate the hydrogen charging rate of the hydrogen storage vessel based on the test values of hydrogen charging time and capacity; the negative deviation from the hydrogen charging rate in the main performance specification sheet provided by the manufacturer shall not be greater than 5%.

7.3 The electrical and electronic equipment in the control, alarm and safety systems of the hydrogen storage system control equipment shall also undergo tests in accordance with the relevant requirements of CCS Guidelines for Type Approval Test of Electric and Electronic Products.

8 Unit/batch inspection

8.1 General requirements

The manufacturer shall conduct routine tests on each set of the hydrogen storage system. The factory test records shall be retained for not less than 20 years or 1.5 times the service life of the product, whichever is longer.

8.2 Hydrogen storage vessel

The batch size for each batch shall be determined by the manufacturer according to the capacity and constituent materials of the metal hydride hydrogen storage device. Two types of batch sizes shall be considered:

- (1) The batch size of the metal hydride is determined by the batch size of the hydrogen-absorbing metal, or approved by CCS;
- (2) The batch size of the hydrogen storage vessel is determined by the batch size defined in the relevant standards for hydrogen storage vessels, or approved by CCS.

8.2.1 Leakage Test

As part of the routine test, each completed hydrogen storage vessel shall undergo a leakage test at the rated charging pressure (RCP) at a temperature of 15–30 °C and shall meet the acceptance criteria.

8.2.2 Burst Test

At least one hydrogen storage vessel shell shall be selected from each batch for a pressure burst test. For hydrogen storage vessels with an internal volume greater than 120 mL, the test method and acceptance criteria of the burst test shall comply with the standard selected for the shell design.

8.2.3 Maximum Delta Pressure Test

At least one set shall be selected from each batch of hydrogen storage vessels for the maximum delta pressure (MDP) test. The MDP of each batch of products shall not exceed 0.8 times the test pressure of the hydrogen storage vessel or 25 MPa, whichever is smaller.

8.3 Hydrogen storage system

The factory test of the hydrogen storage system shall include the following items:

- (1) Visual and Structural Inspection
- (2) Air Tightness Test
- (3) Overpressure Safety Performance Test
- (4) Hydrogen Discharge Performance Test
- (5) Hydrogen Charging Performance Test