Guideline No.:B-09(202612)

Guidelines for Marine Hydrogen Storage, Supply and Bunkering System

Issued date: December 1, 2026

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1 Scope of Application

1.1 This Guideline applies to marine insulated liquid-hydrogen tanks, hydrogen supply system and bunkering system for storing liquid hydrogen with initial para-hydrogen content (volume fraction) ≥95%. High-vacuum multi-layer insulation is generally adopted for the insulation system. The marine liquid-hydrogen storage, supply and bunkering system consists of liquid-hydrogen tank, hydrogen supply system and bunkering system.

1.2 Liquid hydrogen shall be stored under sub-critical state. The design pressure of the inner vessel of the liquid-hydrogen tank shall be no less than 1.0 MPa and no more than 1.2 MPa.

1.3 It is applicable to hydrogen-fuel-powered ships using hydrogen as fuel.

2 Normative References

Provisions of the referenced documents shall constitute provisions of this Guideline by reference herein. For undated references, the latest edition shall apply.

2.1 Resolution MSC.565(108), Revised Interim Recommendations for the Bulk Carriage of Liquefied Hydrogen

2.2 MSC.1/Circ.1647, Interim Guidelines on Safety for Ships Using Fuel-Cell Power Installations

2.3 MSC.1/Circ.1701, Interim Guidelines for the Safety of Ships Using Hydrogen Fuel

2.4 China Classification Society, Rules for Classification of Sea-Going Steel Ships

2.5 China Classification Society, Guidelines for Ships Using Hydrogen Fuel

2.6 GB/T 18443-2010, Test Methods for Performance of Vacuum-Insulated Cryogenic Equipments

2.7 GB/T 150.2-2024, Pressure Vessels — Part 2: Materials

2.8 NB/T 11745-2024, Transportable Vacuum-Insulated Liquid-Hydrogen Pressure Vessels

3 Terms and Definitions

The terms and definitions specified in the above-mentioned normative references shall apply to this Guideline. For convenience of compilation and application, the following definitions are cited and supplemented herein.

3.1 For definitions of terms such as product survey, approval, type test, sample, piece / batch survey, refer to 3.1.2, Chapter 3, Part 1 of Rules for Classification of Sea-Going Steel Ships.

3.2 Para-hydrogen: One of the nuclear spin isomers of hydrogen molecule, in which the spins of atomic nuclei are opposite (anti-parallel).

3.3 Liquid hydrogen: Hydrogen existing in liquid state, which is a colourless and transparent cryogenic liquid. Its normal boiling point is 20.38 K and density at boiling point is 70.77 kg/m³.

3.4 Liquid-state hydrogen storage: A hydrogen-storage mode in which hydrogen gas is converted into liquid hydrogen by cooling below 20.38 K.

3.5 Sub-critical state: A thermodynamic state in which the fluid temperature is lower than its critical temperature, in which both gas and liquid phases can coexist.

3.6 Liquid-hydrogen tank: A cryogenic vessel for storing liquid hydrogen, generally composed of inner vessel, outer shell, insulation structure, connecting mechanical components, measuring instruments, safety facilities, liquid/gas inlet-and-outlet piping and accessories.

3.7 Hydrogen supply system: This system consists of liquid-hydrogen vaporizer, pump, buffer tank, relevant valves, connecting piping, filters, instruments and control system, and supplies clean hydrogen gas at applicable pressure and flow rate to hydrogen-consuming equipment in a safe manner.

3.8 Bunkering system: This system consists of bunkering coupling, vapour return coupling (if fitted), relevant valves, connecting piping, instruments and control system, and is intended for liquid-hydrogen bunkering operation.

3.9 Nominal filling ratio: The maximum designed percentage of allowable liquid-hydrogen filling volume relative to the geometric volume of tank inner vessel under routine filling operations and anticipated service conditions for liquid-hydrogen tanks.

3.10 Filling limit: The ratio of maximum allowable filling volume to the geometric

volume of inner vessel of liquid-hydrogen tank, which shall not be exceeded under any circumstances.

3.11 Gas-sealed liquid barrier structure: It is a physical barrier formed by the hydrostatic pressure of liquid hydrogen itself through specific piping routing or internal-component design for liquid-phase piping led out from the inner vessel of the liquid-hydrogen tank.

4 Drawings and Documents

4.1 The following drawings and documents shall be submitted to CCS for review:

4.1.1 Liquid-hydrogen tank

(1) General assembly drawing of liquid-hydrogen tank;

(2) Drawings of main components: inner vessel and outer shell, head, inter-layer supporting structure for inner vessel and outer shell, reinforcing structure, sloshing-restraint structure (where applicable), piping, lifting lugs, etc.;

(3) List of physical and chemical properties for materials of main pressure-bearing components: materials for inner vessel and outer shell, head, inter-layer piping and inter-layer supports of inner vessel and outer shell, welding consumables, insulation materials, etc.;

(4) Design calculation document: volume calculation, structural-strength calculation for inner vessel and outer shell, structural-strength calculation for inter-layer piping, external-pressure stability calculation, saddle-structure strength calculation, strength calculation for internal and external supporting structures, insulation-performance calculation (where applicable), sloshing-analysis report (where applicable), buckling-analysis report (where applicable), calculation of safe relief quantity and over-pressure relief capacity, lifting-lug strength calculation, weld-joint strength calculation, liquid-hydrogen evaporation-rate calculation;

(5) Finite-element analysis report: global stress analysis of liquid-hydrogen tank, fatigue-stress analysis of liquid-hydrogen tank, stress analysis under mechanical load and thermal-stress load for inner vessel, outer shell and inter-layer piping, fatigue analysis for inner vessel and outer shell, thermodynamic analysis of insulation performance (where applicable);

(6) Insulation arrangement and description, which shall be consistent with insulation-performance calculation or thermodynamic analysis of insulation performance;

(7) Welding procedure and non-destructive-testing procedure;

(8) Risk-analysis report;

(9) Product-performance specification sheet;

(10) Drawing of product name-plate;

(11) Factory-test program.

4.1.2 Hydrogen supply and bunkering system

(1) Process flow diagram for hydrogen supply and bunkering system;

(2) General layout drawing of hydrogen supply and bunkering system;

(3) Drawings of main components: liquid-hydrogen booster pump (where applicable), liquid-hydrogen vaporizer (where applicable), buffer tank, piping and accessories, valves, bunkering port, etc.;

(4) List of physical and chemical properties for materials of main pressure-bearing components: liquid-hydrogen booster pump (where applicable), liquid-hydrogen vaporizer (where applicable), piping, valves, etc.;

(5) Design calculation document: vaporization-capacity matching calculation for liquid-hydrogen vaporizer (where applicable), insulation-performance calculation (where applicable), calculation of safe and over-pressure relief capacity, structural-strength calculation for piping;

(6) Finite-element analysis report: piping stress analysis, fluid-dynamic analysis for layout positions of detection and alarm devices (where applicable), thermodynamic analysis of insulation performance (where applicable);

(7) Drawing and layout drawing of monitoring and alarm system, including layout drawing of monitoring probes, sensors, alarm devices and alarm points, as well as set-values for alarm and control;

(8) Schematic diagram, component list, software functional block diagram, list of alarm types and list of safety action types for control equipment (including control, monitoring and safety system);

(9) Insulation arrangement and description, which shall be consistent with insulation-performance calculation or thermodynamic analysis of insulation performance;

(10) Welding procedure and non-destructive-testing procedure;

(11) Risk-analysis report;

(12) Product-performance specification sheet;

(13) Drawing of product name-plate;

(14) List of alarm and safety-protection items;

(15) Factory-test program;

(16) Where survey is carried out on a project basis, relevant requirements of approved ship drawings shall also be verified.

4.2 The following documents shall additionally be submitted when applying for approval of liquid-hydrogen tank:

(1) Brief introduction of the enterprise, technical characteristics (if any) or basic description of products to be approved;

(2) Simplified process flow of products;

(3) List of main production, inspection and test equipment for products;

(4) Other valid documents, reports and certificates demonstrating the Client’s production capacity and quality level for products within the scope of approval;

(5) Enterprise registration certificate or business license, quality-system certificate or document, qualification certificate and/or production license (if any);

(6) List of suppliers for main raw materials and components (where necessary);

(7) Sample of product certificate of quality;

(8) Key manufacturing-process documents or document list of products;

(9) Approval-test program.

5 Technical Requirements

5.1 General Requirements

5.1.1 The structural design, strength calculation, manufacturing process, arrangement of piping and accessories, system safety and protection of liquid-hydrogen storage, supply and bunkering system shall comply with Guidelines for Ships Using Hydrogen Fuel and accepted standards.

5.1.2 Risk assessment shall be performed for liquid-hydrogen tank, hydrogen supply and bunkering system by appropriate methods (e.g. HAZID, HAZOP, FMEA/FMECA, what-if analysis, etc.). Relevant requirements for risk assessment specified in 1.1.6, Chapter 1, Part 1 of Guidelines for Ships Using Hydrogen Fuel shall be satisfied.

5.1.3 The safety-control system for liquid-hydrogen tank, hydrogen supply and bunkering system shall be designed in accordance with risk-analysis report, and shall be capable of manual and automatic actuation. The explosion-proof classification of electrical, instrument and other accessories shall match the explosion-proof requirements of installation area and shall be no lower than IIC, T1 for hydrogen explosive mixture. Hydrogen and flame detection-alarm devices may be provided according to risk-analysis report or provided independently. Layout positions of detection-alarm devices shall be determined by means such as fluid-dynamic analysis. The detection-alarm devices shall be capable of interlocking the shutdown of the liquid-hydrogen tank, hydrogen supply and bunkering system.

5.1.4 Surfaces of components in contact with hydrogen medium for liquid-hydrogen tank, hydrogen supply and bunkering system shall be subjected to degreasing and cleaning treatment, free of visible solid particulate matters by visual inspection, and residual grease on surfaces shall be no more than 125 mg/m^2. Surfaces of other components shall be subjected to degreasing, rust removal, drying and other treatments and shall comply with provisions of design documents.

5.1.5 The design of inner vessel and outer shell of liquid-hydrogen tank, hydrogen

supply and bunkering system shall take account of thermal-difference stress caused by low-temperature contraction and thermal expansion of materials due to temperature variation during manufacture and service. Compensating devices shall be provided where necessary.

5.1.6 The design temperature of inner vessel of liquid-hydrogen tank, hydrogen supply and bunkering system shall be compatible with liquid-hydrogen medium. The minimum design temperature of outer shell shall take account of liquid-hydrogen leakage or degradation of insulation capacity, and the design temperature of outer shell shall be no higher than operating temperature of inner vessel. Under normal operating conditions, the volume fraction of oxygen in the space containing cryogenic surfaces at or below −183 ℃ shall be kept below 1 %. If this requirement cannot be achieved, structural materials and auxiliary equipment (e.g. thermal-insulation materials) around and below cryogenic surfaces shall be compatible with high-oxygen-concentration environment.

5.1.7 The selected insulation mode for liquid-hydrogen tank, hydrogen supply and bunkering system shall satisfy designed performance requirements, and possibility of premature degradation of insulation performance at anticipated carriage temperature of liquid hydrogen shall be considered. Appropriate safety measures shall be considered if single damage may lead to reduction of insulation capacity.

5.1.8 Pre-cooling and inerting of liquid-hydrogen tank, hydrogen supply and bunkering system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.1.9 The control, monitoring and safety system of liquid-hydrogen tank, hydrogen supply and bunkering system shall comply with relevant requirements specified in Chapter 12, Part 1 of Guidelines for Ships Using Hydrogen Fuel.

5.2 Requirements for Liquid-Hydrogen Tank

5.2.1 The nominal filling ratio of liquid-hydrogen tank shall not exceed 90 %, and the filling limit shall not exceed 95 %. An overflow outlet shall be provided to prevent over-bunkering in accordance with requirements for nominal filling ratio. Liquid-hydrogen tanks with volume less than 10 m^3 shall be fitted with over-fill prevention devices.

5.2.2 Flow direction and service purpose shall be marked on piping such as liquid-phase

nozzles, gas-phase nozzles and loading/unloading nozzles of liquid-hydrogen tank. Liquid-hydrogen tank shall be fitted with no less than two (sets of) pressure relief valves including one (set of) standby unit. The relief capacity of each (set of) pressure relief valve shall satisfy requirements from calculation of safe and over-pressure relief capacity, and shall satisfy performance requirements such as insulation, tightness and medium compatibility for liquid hydrogen. The pressure relief valve shall keep the internal pressure of inner vessel no more than 20 % of Maximum Allowable Relief Valve Setting (MARVS), and its set pressure shall be lower than critical pressure of liquid hydrogen. The scenario that rapid degradation of insulation-system capacity causes fast temperature rise and accelerated vaporization of liquid hydrogen inside tank which may exceed capacity of pressure relief valves shall be taken into consideration.

5.2.3 The design pressure of inter-layer piping for liquid-hydrogen tank shall be no less than design pressure of inner vessel. It shall be flexibly designed to avoid fatigue cracking and damage induced by thermal expansion-contraction, mechanical chattering or vibration. Compensating devices or fastening devices shall be provided where necessary. Its joints shall adopt equal-wall-thickness full-penetration butt-welded construction, and butt joints with permanent backing strips shall not be used. The fixed end of inter-layer supporting structure shall preferably be arranged on the side with concentrated piping layout, and the movable end shall have sufficient displacement for cold contraction and possess good insulation performance.

5.2.4 Anti-impingement baffles may be fitted at outlet ends of bottom liquid inlet-outlet piping of liquid-hydrogen tank inner vessel. Spray devices shall be fitted at outlet ends of top liquid-inlet piping inside inner vessel. The spray pipe shall extend to at least 80 % of inner-vessel length, and total cross-sectional area of spray holes shall be no less than internal cross-sectional area of spray pipe. The outlet end of spray piping shall minimize injection of incoming liquid hydrogen into adjacent gas-phase piping and direct impingement against inner surfaces of heads and cylinder shell.

5.2.5 Liquid-outlet piping of liquid-hydrogen tank shall be led out from bottom of inner vessel, and gas-sealed liquid barrier structure shall be provided for liquid-phase piping led out from inner vessel. A drain outlet shall be fitted on liquid-hydrogen tank for complete draining of liquid and possible solid particulate impurities contained in liquid hydrogen inside inner vessel.

5.2.6 Hydrogen vent pipe and purging nozzle shall be provided. The vent pipe of liquid-hydrogen tank shall be arranged at top, fitted with devices to prevent air

back-flow, ingress of rain and snow, and blockage by condensates and foreign objects. Discharge velocity of hydrogen shall be controlled to prevent fire, explosion and other accidents. Vent pipes for liquid-hydrogen tank, hydrogen supply and bunkering system shall be sloped.

5.2.7 The relief pressure of safety-relief device for outer shell shall be no more than 0.05 MPa. Its discharge capacity shall be sufficient to limit inter-layer pressure no higher than 0.1 MPa. Its total discharge area shall be no less than product of geometric volume of inner vessel (m^3) multiplied by 341 mm^2/m^3 and may not exceed 5000 mm^2. Its design and arrangement shall minimize massive ingress of air into inter-layer space upon actuation and prevent blockage by insulation materials. Appropriate fixing and protection measures shall be provided.

5.2.8 Pressure and temperature control for liquid-hydrogen tank shall comply with requirements specified in Section 9, Chapter 3, Part 1 of Guidelines for Ships Using Hydrogen Fuel.

5.2.9 Safety valves or other relief devices shall be fitted on piping where liquid hydrogen may be trapped, and their set pressure shall not exceed design pressure of piping.

5.2.10 Structural strength of saddles for liquid-hydrogen tank shall satisfy design requirements, and effects caused by insulation loss shall be taken into consideration.

5.2.11 The design service life of liquid-hydrogen tank shall be no less than the greater of the ship design service life and 20 years.

5.3 Requirements for Hydrogen Supply and Bunkering System

5.3.1 No stop valve shall be installed between safety valve or other relief device and the protected liquid-hydrogen tank, hydrogen supply and bunkering system.

5.3.2 A stop valve shall be fitted as close as practicable to liquid-hydrogen tank between liquid-hydrogen tank and hydrogen supply and bunkering system, and no other accessories shall be arranged on piping between stop valve and liquid-hydrogen tank.

5.3.3 The hydrogen supply and bunkering system shall be fitted with manual shut-off valve and fail-safe emergency shut-off valve (or fail-safe emergency shut-off valve with manual shut-off function), as well as main fuel shut-off valve for automatic hydrogen

supply cut-off. Manual valves shall be arranged at accessible positions. Emergency shut-off devices shall comply with relevant requirements of NB/T 11745.

5.3.4 Effective insulation measures shall be adopted for piping of hydrogen supply and bunkering system to prevent outer surface temperature of piping from dropping below 90 K (−183 ℃), so as to avoid formation of oxygen-rich condensate by condensation of atmospheric oxygen.

5.3.5 Piping design for hydrogen supply and bunkering system shall control flow velocity of saturated hydrogen vapour no more than 16 m/s to satisfy safety and service requirements.

5.3.6 The hydrogen supply and bunkering system shall be properly earthed. Good contact without loosening shall be maintained among earthing device, earthing conductor, earthing wire and earthing point. The static-electricity earthing shall preferably share common earth electrode with other earthing circuits. If dedicated static-electricity earthing is adopted, earthing resistance for liquid-hydrogen system shall be no more than 1 Ω. Flange joints on hydrogen piping shall be bonded with metal jumpers, and bonding resistance shall be less than 0.03 Ω.

5.3.7 Except for piping directly communicating with outside atmosphere, purging-inerting nozzles shall be provided for remaining piping of hydrogen supply and bunkering system. Nozzle positions shall enable sufficient purging and inerting (by nitrogen or inert gas) of gas inside each piping segment. Purging and inerting shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.3.8 To meet gaseous hydrogen supply demand, hydrogen supply and bunkering system may be equipped with liquid-hydrogen vaporizer, single-stage or multi-stage liquid-hydrogen booster pumps and other auxiliary equipment.

5.3.9 Ambient-air vaporizer (AAV) shall not be adopted for liquid-hydrogen vaporizer; water-bath vaporizer with dry-burn-out protection is recommended. The design pressure of liquid-hydrogen vaporizer shall be no less than 1.2 times the maximum working pressure. Its vaporization capacity shall satisfy maximum flow-rate requirement of liquid-hydrogen booster pump. Devices shall be fitted on upstream and downstream piping to prevent back-flow of high-pressure hydrogen into liquid-hydrogen piping. Temperature and pressure monitoring devices as well as automatic or manual stop valves shall be arranged at outlet of liquid-hydrogen vaporizer. The safety-control system shall cut off liquid-hydrogen supply when low temperature

is detected downstream of liquid-hydrogen vaporizer.

5.3.10 Easily-removable filter unit with filtration accuracy ≤5 μm shall be fitted upstream of liquid-inlet port of liquid-hydrogen booster pump. Maintenance valves shall be fitted on both sides, and flow-path cross-sectional area shall satisfy liquid-inlet flow-rate requirement of booster unit.

5.3.11 Check valve and full-lift enclosed safety valve shall be arranged on outlet piping of liquid-hydrogen booster pump. Temperature and pressure monitoring devices shall be fitted at pump outlet. Upon parameter over-limit, safety-control system shall trigger immediate alarm and interlock pump shutdown.

5.3.12 According to layout of liquid-hydrogen vaporizer and liquid-hydrogen booster pump, hydrogen supply and bunkering system may be divided into cryogenic-low-pressure section, cryogenic-high-pressure section, high-temperature-high-pressure section and high-temperature-low-pressure piping section based on temperature and pressure conditions. Isolation valves may be provided at junctions of high-pressure and low-pressure piping sections. Connection segments shall be kept as short as practicable to minimize dead volume, and insulation treatment shall be implemented for connection joints.

5.3.13 Fittings such as hydrogen hoses and double-wall piping shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.3.14 The control, monitoring and safety system for hydrogen supply and bunkering system shall realize ventilation monitoring, vacuum and inerting monitoring, cryogenic monitoring, gas detection and safety functions, and shall comply with relevant requirements specified in Part 4 and Chapter 2 of Part 7 of Rules for Classification of Sea-Going Steel Ships and Chapter 12, Part 1 of Guidelines for Ships Using Hydrogen Fuel.

5.4 Design Calculation Requirements

5.4.1 Inner vessel, outer shell, inter-layer piping of liquid-hydrogen tank and piping of hydrogen supply and bunkering system shall comply with relevant requirements specified in Chapter 3 and Section 2, Chapter 4, Part 1 of Guidelines for Ships Using Hydrogen Fuel. They shall withstand mechanical loads (including pressure loads such as internal pressure, external pressure, differential pressure, gravity load, inertia load, dynamic load) and thermal-stress loads under various service conditions which may

occur during normal loading-unloading and transportation, and the most severe combination of these loads shall be considered.

5.4.2 For inner vessel and outer shell of liquid-hydrogen tank, anticipated design service life, corrosion rate and erosion rate of materials exposed to liquid hydrogen shall be taken into account. Fatigue failure induced by repeated application of loads described in 5.4.1 shall also be considered to ensure corrosion allowance satisfies requirement for design service life.

5.4.3 The inter-layer supporting structure of liquid-hydrogen tank and local shell areas subjected to its reaction force shall possess sufficient strength and rigidity, and shall maintain sufficient stability under combined compression and bending loads.

5.4.4 Appropriate methods shall be adopted for design calculation of insulation performance for liquid-hydrogen tank (insulation-performance calculation or thermodynamic analysis of insulation performance). Where effective design calculation for insulation performance cannot be performed, test method may be used for determination, and such test method shall be submitted to CCS for approval.

5.4.5 Saddles for liquid-hydrogen tank shall be designed and calculated in accordance with maximum anticipated static and dynamic inclination angles as well as maximum anticipated acceleration values, taking ship characteristics and tank location into consideration.

5.5 Material Requirements

5.5.1 Suitable materials shall be used for parts in contact with liquid hydrogen. Materials shall be hydrogen-compatible to prevent structural damage caused by hydrogen embrittlement, degradation of strength and fatigue performance from continuous exposure to liquid-hydrogen environment; materials shall be oxygen-compatible to mitigate potential risks of oxygen-rich environment induced by liquid-hydrogen leakage or insulation-capacity degradation; compatibility with adjacent materials shall be considered; sufficient ductility and strength shall be guaranteed.

5.5.2 Where steel is adopted for liquid-hydrogen tank, it shall comply with GB/T 150.2, and ferrite-content measurement may refer to NB/T 11745. The ferrite content of stainless-steel plates, steel forgings and steel pipes for inner vessel and hydrogen-contact pressure-bearing piping shall be no more than 3 %. The ferrite

content of formed fittings, heads and bent piping in contact with hydrogen shall be no more than 5 %. Where other materials (e.g. aluminium and its alloys, copper alloys, titanium alloys, etc.) are used for liquid-hydrogen-contact components, detailed material data (including chemical composition, tensile property, impact toughness and material-compatibility statement) shall be submitted to CCS for approval.

5.5.3 Supports between inner vessel and outer shell may adopt metallic or non-metallic materials satisfying service and performance requirements under liquid-hydrogen conditions. If metallic materials are selected, materials with low thermal conductivity and good cryogenic impact toughness shall be adopted. If non-metallic materials are selected, materials with low thermal conductivity, service temperature within allowable temperature range and good cryogenic impact toughness shall be adopted. Non-metallic materials such as epoxy fiberglass-reinforced plastics may be used as supporting materials, and inspection items and test values shall comply with relevant requirements of NB/T 11745.

5.5.4 Supports or pedestals for liquid-hydrogen tank shall be made of non-combustible materials suitable for cryogenic service (design temperature at least equal to that of outer shell), and shall satisfy fire-resistance and strength requirements specified by design.

5.5.5 Selection of welding consumables shall take account of matching of mechanical properties of welded joints with base metal of liquid-hydrogen tank, and shall comply with Appendix E of GB/T 150.2. Materials for non-pressure-bearing components welded to pressure-bearing components shall possess good toughness and weldability and shall be compatible with the mating pressure-bearing components.

5.6 Manufacturing Requirements

5.6.1 Surfaces of liquid-hydrogen tank, hydrogen supply and bunkering system shall be smooth and neat, free of dents, cracks, welding slags, paint peeling and other defects. Safety-relief devices, pressure and liquid-level instruments shall be reasonably arranged with clear marking.

5.6.2 Welding-procedure qualification shall be performed under supervision of CCS surveyor for first-time manufacture or adoption of new welding procedure.

5.6.3 All joints of outer shell shall be welded with full-penetration weld. In-plane butt weld shall be adopted for all outer-shell joints wherever practicable. Where in-plane

butt weld is impracticable due to manufacturing process and structure of outer shell, full-penetration T-joint welding may be adopted based on test results obtained during welding-procedure approval.

6 Raw Materials and Components

Raw materials and components of products shall be controlled in accordance with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

7 Type Test

Type test shall be carried out for liquid-hydrogen tank in accordance with requirements of this Clause. For liquid-hydrogen storage, supply and bunkering system, piece / batch survey shall be performed in accordance with approved drawings in conjunction with ship-board projects.

Type- test Items for Liquid- Hydrogen Tank Table 7.1

No.	Test Item and Sequence	Test Requirements
1.	Inspection of Main Raw Materials and Components	7.2
2.	Welding Inspection	7.3
3.	Product Weld Test and Non- Destructive Testing	7.4
4.	Visual and Dimensional Inspection	7.5
5.	Pressure Test for Inner Vessel, Outer Shell and Inter- layer Piping	7.6
6.	Tightness Test	7.7
7.	Cleanliness Inspection	7.8
8.	Vacuum- degree and Helium Mass- Spectrometer Leak Detection	7.9

9.	Leak- rate Test for Vacuum Inter- layer	7.10
10.	Out- gassing- rate Test for Vacuum Inter- layer	7.11
11.	Hold- time Test	7.12
12.	Cold- fill Test	7.13

7.1 Selection of Representative Sample

7.1.1 When applying for product approval of liquid-hydrogen tank, type test shall be performed in accordance with items and requirements specified in 7.2-7.13. The product for type test shall be manufactured under surveyor's supervision, in compliance with CCS-approved welding procedure and CCS-approved drawings, and its characteristics and manufacturing quality shall represent or cover the scope of factory application for approval (selection may be based on base material, design pressure, design temperature, wall thickness, outer diameter, volume, insulation mode, etc.).

7.2 Inspection of Main Raw Materials and Components

7.2.1 Validity of certificates for main raw materials and components shall be verified for compliance with this Guideline, CCS-approved drawings and CCS requirements, and consistency between certificates and actual materials shall be checked. Where re-test is performed for raw materials, test items and results of raw materials shall comply with requirements of this Guideline and CCS.

7.3 Welding Inspection

7.3.1 To guarantee tightness of outer shell, equivalent welding requirements for inner vessel shall be applied to outer shell wherever practicable. All joints of outer shell shall be full-penetration welded and shall satisfy manufacturing requirements specified in 5.6.3.

7.3.2 Welding inspection shall at least cover main butt welds and full-penetration T-joints and other principal welds of inner vessel, outer shell and piping for hydrogen supply and bunkering system, including pre-weld inspection, welding operation and post-weld inspection. Mode, duration and temperature for pre-heat before welding and post-weld heat retention shall comply with CCS-approved welding-procedure

specification or process documents. Pre-weld inspection, welding and post-weld inspection shall comply with requirements of this Guideline, CCS-approved drawings and CCS.

7.4 Product Weld Test and Non-Destructive Testing

7.4.1 Product weld test shall be performed for liquid-hydrogen tank, hydrogen supply and bunkering system during manufacture in compliance with Guidelines for Ships Using Hydrogen Fuel. Test items mainly include transverse tensile test of weld, longitudinal tensile test of weld, bend test, impact test and macroscopic examination of weld cross-section (where necessary). Specimen sampling positions, test requirements and test results shall comply with relevant CCS requirements.

7.4.2 Non-destructive testing shall be performed for welds of liquid-hydrogen tank, hydrogen supply and bunkering system after welds have cooled down to ambient temperature, and shall be carried out after post-weld heat treatment where applicable. Non-destructive-testing procedure and acceptance criteria shall be submitted to CCS for approval. Where higher standards or tolerances are assumed in design, such requirements shall also be satisfied. Radiographic testing shall in principle be used for detection of internal defects. Approved ultrasonic testing may substitute radiographic testing, but additional radiographic testing shall be performed on selected locations for result verification. Records of radiographic and ultrasonic testing shall be kept.

7.5 Visual and Dimensional Inspection

7.5.1 Upon completion of manufacture of liquid-hydrogen tank, surface quality shall be inspected and surfaces shall be free of scars.

7.5.2 Principal dimensions of liquid-hydrogen tank such as out-of-roundness of inner vessel and outer shell and main overall dimensions shall comply with CCS-approved drawings, CCS requirements and relevant standards.

7.6 Pressure Test for Inner Vessel, Outer Shell and Inter-layer Piping

7.6.1 Hydrostatic test shall be performed separately for inner vessel, outer shell and inter-layer piping of liquid-hydrogen tank. Hydrostatic test is generally adopted. Chloride-ion content in test water shall be controlled to no more than 15 mg/L. Test pressure shall be no less than 1.5 times design pressure with holding-pressure duration no less than 30 min. Upon completion of hydrostatic test, test liquid shall be fully

drained, and interiors of inner vessel, outer shell and inter-layer piping shall be blow-dried and cleared of foreign debris.

7.6.2 Pneumatic test is permitted for inner vessel, outer shell and inter-layer piping of liquid-hydrogen tank. Pressure shall be increased slowly during test. Hold pressure for 5 min at 10 % of 1.5 times design pressure, and perform leakage inspection on all welded joints and connection points. After no-leakage confirmation, raise pressure to 50 % of 1.5 times design pressure. If no abnormality occurs, raise pressure step-by-step by each step of 10 % of 1.5 times design pressure up to 1.5 times design pressure and hold for 10 min. Then reduce pressure down to design pressure and hold for no less than 30 min.

7.6.3 No leakage and no visible deformation shall occur to inner vessel, outer shell and inter-layer piping during pressure test. After pressure test, besides visual inspection, non-destructive testing shall be performed on critical locations. Locations and scope of testing shall be subject to surveyor’s approval.

7.6.4 Strain measurement shall be performed where calculation shows that primary membrane stress exceeds 75 % of material yield strength. Strain gauges shall be attached to designated internal and external positions of tank before hydrostatic test, and strain-stress shall be monitored throughout test for verification of calculation results. Strain measurement is normally performed on the first unit among a series of identical tanks to be manufactured.

7.7 Tightness Test

7.7.1 After pressure test for inner vessel and inter-layer piping, tightness test shall be performed to verify satisfactory tightness.

7.7.2 Helium gas or mixture of 5 % hydrogen and 95 % nitrogen shall be used as test medium for tightness test. Test pressure shall be design pressure and holding-pressure duration shall be no less than 30 min. Leakage rate during test shall not exceed limits specified in CCS-approved drawings.

7.7.3 If pressure test and tightness test adopt identical test medium, tightness test may be combined with pressure test specified in Clause 7.6 of this Guideline.

7.8 Cleanliness Inspection

7.8.1 Cleanliness inspection for inner vessel, outer shell and inter-layer piping shall comply with requirements specified in 5.1.4 of this Guideline, CCS-approved drawings and relevant standards.

7.9 Vacuum-degree and Helium Mass-Spectrometer Leak Detection

7.9.1 After assembly of inner vessel and outer shell, vacuum-degree and helium mass-spectrometer leak detection shall be carried out for vacuum inter-layer. Leak-rate indexes shall comply with CCS-approved drawings and relevant standards. Leakage points shall be repaired in accordance with CCS-approved repair-welding procedure, and re-testing shall be performed after passing non-destructive-testing requirements of this Guideline.

7.10 Leak-rate Test for Vacuum Inter-layer

7.10.1 Test method for leak rate of tank inter-layer and inter-layer of vacuum-insulated piping shall comply with GB/T 18443.3.

7.11 Out-gassing-rate Test for Vacuum Inter-layer

7.11.1 Test method for out-gassing rate of vacuum inter-layer shall comply with GB/T 18443.4.

7.12 Hold-time Test

7.12.1 Hold-time test shall be performed in accordance with relevant requirements of NB/T 11745. The hold-time shall keep pressure of liquid-hydrogen tank below set pressure of safety-relief device for 15 consecutive days. Where ship voyage duration exceeds 15 days, hold-time shall be no less than maximum voyage duration.

7.13 Cold-fill Test

7.13.1 Liquid nitrogen is normally adopted as test medium for cold-fill test. Filling quantity shall not exceed nominal filling ratio, and parts of tank which would contact liquid hydrogen shall be sufficiently cooled. After filling completion, the tank shall stand for no less than 48 hours.

7.13.2 During filling and standing period, each part of liquid-hydrogen tank shall be monitored for cold-leakage, frost formation, visible deformation, fracture and other

conditions. Temperature difference between adjacent areas on outer-shell surface shall not exceed 5 ℃, except for locations where piping penetrates outer shell and locations under direct solar radiation.

8 Piece / Batch Survey

8.1 Works Approval shall be obtained for liquid-hydrogen tank. Piece / Batch survey after approval shall be carried out in accordance with product survey plan approved at time of approval. Test items shall include the following:

(1) Inspection of Main Raw Materials and Components;

(2) Welding Inspection;

(3) Product Weld Test and Non-Destructive Testing;

(4) Visual and Dimensional Inspection;

(5) Pressure Test for Inner Vessel, Outer Shell and Inter-layer Piping;

(6) Tightness Test;

(7) Cleanliness Inspection;

(8) Vacuum-degree and Helium Mass-Spectrometer Leak Detection;

(9) Leak-rate Test for Vacuum Inter-layer;

(10) Out-gassing-rate Test for Vacuum Inter-layer.

8.2 Piece / Batch Survey for liquid-hydrogen supply and bunkering system shall be carried out in conjunction with ship-board projects in accordance with approved drawings and test program. Specific test items shall include the following:

8.2.1 Visual and Structural Inspection

Visual inspection and routine review of design drawings, specifications and other documents shall be performed to verify conformity between fabrication and approved drawings.

8.2.2 Pressure Test

Nitrogen shall be used as the test medium for the pressure resistance test of the piping of hydrogen supply and bunkering system. Connect the piping of hydrogen supply and bunkering system to the gas source, replace the safety valve with a plug, and gradually raise the pressure to 1.5 times the design pressure and hold for 30 min. The test is acceptable if no leakage, visible deformation or abnormal noise occurs during pressure holding.

8.2.3 Tightness Test

Nitrogen shall be used as the test medium for the tightness test of hydrogen supply and bunkering system. Connect the hydrogen supply and bunkering system to the gas source. After confirming no visible bubbles, increase the pressure stepwise up to the maximum working pressure and hold for 12 h. During the test, the pressure drop after temperature correction shall not exceed 1 % of the test pressure and shall not exceed 0.05 MPa.

8.2.4 Piping Thermal Insulation Inspection

Piping thermal insulation inspection shall be carried out in accordance with the thermal insulation construction manual provided by the insulation designer or insulation material manufacturer, and inspection items may be agreed by all parties.

8.2.5 System Function, Monitoring and Alarm Test

Verify that the hydrogen supply and bunkering system fulfills the relevant functions specified in Clause 5.3.

Part 2

Marine Solid-State Hydrogen Storage, Supply and Bunkering System

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1 Scope of Application

1.1 This Guideline applies to marine solid-state hydrogen storage, supply and bunkering system adopting metal hydride hydrogen storage such as titanium-based, vanadium-based, magnesium-based, zirconium-based and rare-earth-based, with operating ambient temperature ranging from −40 ℃ to 65 ℃. The system consists of hydrogen storage system composed of one or multiple hydrogen storage units, hydrogen supply system and bunkering system.

1.2 The maximum developed pressure (MDP) of the metal-hydride hydrogen storage device shall not exceed 25 MPa.

1.3 It is applicable to hydrogen-fuel-powered ships using hydrogen as fuel.

2 Normative References

Provisions of the referenced documents shall constitute provisions of this Guideline by reference herein. For undated references, the latest edition shall apply.

2.1 China Classification Society, Rules for Classification of Sea-Going Steel Ships

2.2 China Classification Society, Rules for the Construction of Inland Steel Ships

2.3 China Classification Society, Rules for Materials and Welding

2.4 China Classification Society, Guidelines for Ships Using Hydrogen Fuel

2.5 China Classification Society, Guidelines for Type Approval Test of Electrical and Electronic Products

2.6 ISO 14687:2019, Hydrogen fuel — Product specification

2.7 ISO 16111:2018, Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride

2.8 GB/T 29729-2022, Essential Requirements for the Safety of Hydrogen Systems

2.9 GB/T 3634.2-2025, Hydrogen — Part 2: Pure hydrogen, high-purity hydrogen and ultra-high-purity hydrogen

2.10 GB/T 33291-2016, Measurement method for pressure-composition-temperature (P-C-T) for reversable hydrogen absorption& desorption of hydrides

3 Terms and Definitions

The terms and definitions specified in the above-mentioned normative references shall apply to this Guideline. For convenience of compilation and application, the following definitions are cited and supplemented herein.

3.1 For definitions of terms such as product survey, approval, type test, sample, piece / batch survey, refer to 3.1.2, Chapter 3, Part 1 of Rules for Classification of Sea-Going Steel Ships.

3.2 Batch: Products of identical specification continuously manufactured by the same manufacturer on the same production line with identical production processes.

3.3 Solid-state hydrogen storage: Hydrogen storage mode where hydrogen chemically reacts with solid-state substances.

3.4 Metal hydride: Solid material formed by combination of metal or alloy with hydrogen gas, capable of absorbing and desorbing hydrogen.

3.5 Hydrogen storage bed assembly: Structural assembly installed inside hydrogen storage vessel, composed of metal hydride, heat-conducting agent, anti-expansion agent, gas-conducting components and other materials and parts. It performs reversible hydrogen absorption-desorption, improves heat and mass transfer, and prevents over-pressure expansion, pulverization and migration of hydrogen storage materials.

3.6 Hydrogen storage vessel: Enclosure of any shape (cylindrical, prismatic, cubic, etc.) designed to contain hydrogen gas, metal hydride and other internal components of hydrogen storage vessel. It may be gas cylinder, pressure vessel or other pressure-resistant containers.

3.7 Hydrogen storage unit: Single hydrogen storage device adopting metal-hydride medium for reversible hydrogen storage / desorption, including hydrogen storage vessel, hydrogen storage bed assembly, valves, heat-exchange structures, etc.

3.8 Hydrogen storage system: A system composed of one or multiple hydrogen storage units, including hydrogen storage units, pressure relief devices, stop valves, connecting

piping, instruments and control system.

3.9 Hydrogen supply system: Consisting of relevant valves, connecting piping, instruments and control system, which supplies clean hydrogen gas at applicable pressure and flow rate to hydrogen-consuming equipment in a safe manner.

3.10 Bunkering system: Consisting of bunkering coupling, vapour return coupling (if fitted), relevant valves, connecting piping, instruments and control system, for bunkering of hydrogen storage system.

3.11 Pressure relief device: Device intended to prevent rupture of hydrogen sto rage unit under over-pressure or fire exposure conditions. The pressure relief d evice may be pressure-actuated, i.e. set to activate at a specified pressure; or t emperature-actuated, i.e. set to activate at a specified temperature; or combined pressure-and-temperature-actuated.

3.12 Pressure relief valve: Resettable pressure relief device.

3.13 Nominal hydrogen storage capacity: Maximum hydrogen desorption quantity deliverable by metal-hydride hydrogen storage device under technical conditions specified by manufacturer.

3.14 Water volume: Total internal cavity volume of hydrogen storage vessel without the hydrogen storage bed assembly installed.

3.15 Maximum developed pressure (MDP): MDP shall be determined according to temperature-pressure characteristics of metal hydride at maximum operating temperature. It refers to the maximum gauge gas pressure reached at equilibrium at maximum service temperature after metal-hydride hydrogen storage device absorbs hydrogen up to nominal capacity. Under any circumstances, the stress level under MDP shall not exceed 80 % of yield strength of hydrogen storage vessel.

3.16 Rated Charging Pressure (RCP): Maximum gauge hydrogen charging pressure of metal-hydride hydrogen storage system under specified conditions.

Note: RCP is generally not equal to equilibrium plateau pressure of hydrogen-absorbing alloy. RCP shall be determined from temperature-pressure characteristics to prevent vessel wall stress of hydrogen storage vessel from exceeding design stress limit induced by pressure generated during hydrogen charging.

3.17 Stress level under Maximum developed pressure (MDP): Sum of all stresses induced on vessel shell wall by metal hydride, hydrogen gas under MDP and any other applicable mechanical loads at nominal capacity.

3.18 Gravimetric hydrogen storage density: Ratio of nominal hydrogen storage capacity to total mass of hydrogen storage system, expressed in wt%.

3.19 Volumetric hydrogen storage density: Ratio of nominal hydrogen storage capacity to volume of hydrogen storage system, expressed in kg/m^3 or g/L.

3.20 Room temperature: 15 ℃ ~ 30 ℃.

4 Drawings and Documents

4.1 The following drawings and documents shall be submitted to CCS for review:

4.1.1 Hydrogen Storage and Supply System

(1) System flow diagram;

(2) Product technical specification and main performance data sheet;

(3) Detailed parameters, drawings and list of physical and chemical properties for piping system, including heat-exchange tubes, high-pressure bellows, pressure-relief piping and vent piping, etc.;

(4) Piping strength calculation document;

(5) Drawings and descriptions for flanges, valves and other devices;

(6) Relevant process documents for piping system, including but not limited to welding and non-destructive-testing;

(7) Technical documents for piping pressure test (strength test and tightness test);

(8) System schematic drawing and layout drawing of monitoring and alarm system, including layout drawing of monitoring probes, sensors, alarm devices and alarm points, as well as set-values for alarm and control;

(9) Schematic diagram, component list, software functional block diagram, list of alarm types and list of safety action types for control equipment (including control, monitoring and safety system);

(10) Performance test program for hydrogen storage and supply system, including function verification for valves, accessories and operation-related equipment;

(11) External piping connection drawing;

(12) Flow-pressure diagram during hydrogen desorption of hydrogen storage system

(13) Whole-service-life performance description for hydrogen storage and supply system (performance variation over service life);

(14) Failure Mode and Effects Analysis (FMEA) report for hydrogen storage, supply and bunkering system;

(15) Stress analysis report for hydrogen storage and supply piping and bunkering piping;

(16) System specification or operation manual;

(17) Nameplate drawing (indicating at least main parameters such as nominal capacity, nominal hydrogen desorption flow rate, rated charging pressure, nominal hydrogen charging rate, hydrogen-storage material code, heat-exchange type code, etc.);

(18) List of necessary auxiliary equipment (if any);

(19) Where survey is carried out on a project basis, relevant requirements of approved ship drawings shall also be verified.4.1.2 Hydrogen Storage Unit

(1) Main product performance data sheet, including but not limited to nominal capacity, nominal hydrogen desorption flow rate, rated charging pressure, nominal hydrogen charging rate, hydrogen-storage material code, heat-exchange type code and other main parameters;

(2) General assembly drawing and main component drawings;

(3) Strength calculation document and pressure-relief-device calculation document;

(4) List of physical and chemical properties for main pressure-bearing components;

(5) Characteristic description of hydrogen-storage materials (e.g. titanium-based, vanadium-based, magnesium-based, zirconium-based, rare-earth-based, etc.), including P-C-T data;

(6) Stress analysis report for hydrogen storage vessel (where applicable);

(7) Manufacturing process documents, including but not limited to filling process, reaction-bed forming process, activation process (for titanium-based, zirconium-based, vanadium-based, magnesium-based, rare-earth-based materials, etc.).

4.1.3 Bunkering System

(1) General layout drawing of bunkering system;

(2) Drawings of main components: piping and accessories, valves, bunkering port, etc.;

(3) List of physical and chemical properties for main pressure-bearing components: piping, valves, etc.;

(4) Design calculation document: calculation of safe and over-pressure relief capacity, structural-strength calculation for piping;

(5) System schematic drawing and layout drawing of monitoring and alarm system, including layout drawing of monitoring probes, sensors, alarm devices and alarm points, as well as set-values for alarm and control;

(6) Schematic diagram, component list, software functional block diagram, list of alarm types and list of safety action types for control equipment (including control, monitoring and safety system);

(7) Risk-analysis report;

(8) Product-performance specification sheet.

4.2 The following documents shall additionally be submitted when applying for approval of hydrogen storage unit:

(1) Brief introduction of the enterprise, technical characteristics (if any) or basic description of products to be approved;

(2) Simplified process flow of products;

(3) List of main production, inspection and test equipment for products;

(4) Other valid documents, reports and certificates demonstrating the Client's production capacity and quality level for products within the scope of approval;

(5) Enterprise registration certificate or business license, quality-system certificate or document, qualification certificate and/or production license (if any);

(6) List of suppliers for main raw materials and components (where necessary);

(7) Sample of product certificate of quality;

(8) Key manufacturing-process documents or document list of products;

(9) Approval-test program.

5 Technical Requirements

5.1.1 The structural design, strength calculation, manufacturing process, arrangement of piping and accessories, system safety and protection of marine solid-state hydrogen storage, supply and bunkering system shall comply with Guidelines for Ships Using Hydrogen Fuel and standards accepted by CCS.

5.1.2 Welding-procedure approval

For hydrogen storage vessels and piping of welded construction, welding-procedure approval shall be performed under supervision of CCS surveyor.

5.2 System Design

5.2.1 Risk control for design of hydrogen storage, supply and bunkering system shall comply with Clause 7.2 of GB/T 29729.

5.2.2 The hydrogen storage, supply and bunkering system shall preferably adopt

modular structure convenient for assembly, inspection and maintenance, and shall make reasonable use of heat generated from operation of other equipment.

5.2.3 The hydrogen storage, supply and bunkering system shall be provided with safety accessories including but not limited to pressure relief devices and stop valves, which shall comply with requirements of GB/T 29729.

5.2.4 Temperature monitoring devices and pressure monitoring devices shall be reasonably arranged for hydrogen storage, supply and bunkering system.

5.2.5 Except for piping directly communicating with outside atmosphere, purging-inerting nozzles shall be provided for remaining piping of hydrogen supply and bunkering system. The positions of nozzles shall enable sufficient purging and inerting (by nitrogen or inert gas) of gas inside each piping segment.

5.2.6 For hydrogen storage systems adopting active cooling system to control and/or influence system temperature, no liquid leakage shall occur between hydrogen storage vessel and cooling system. The cooling medium shall not cause harmful chemical reaction with metal hydride. Where there exists possibility of contact between cooling medium and metal hydride, appropriate risk assessment shall be carried out.

5.2.7 Effective measures shall be taken to prevent particulate matter from impairing functions of valves or pressure relief devices, and ensure that hydrogen storage and supply system can meet requirements of fire test.

5.2.8 Hydrogen-involved piping in hydrogen storage, supply and bunkering system shall comply with Guidelines for Ships Using Hydrogen Fuel, and thermal expansion-contraction compensation structure shall be considered.

5.2.9 Quality indicators of hydrogen released from hydrogen storage system shall meet technical requirements specified by manufacturer of hydrogen storage system and shall be compatible with requirements of matched hydrogen-consuming equipment.5.2.10 Hydrogen storage system shall not be filled with hydrogen (or hydrogen shall be fully desorbed) during transportation. Hydrogen charging and desorbing operations shall only be performed for hydrogen storage systems fixedly installed on board ships.

5.3 Hydrogen Storage System

5.3.1 Arrangement

5.3.1.1 Hydrogen storage system shall be arranged to minimize risk of damage after collision or grounding, and shall preferably be arranged as close as practicable to ship centre-line.

5.3.1.2 When hydrogen storage units are connected to ship-board systems, their supporting and fixing devices shall be designed in accordance with maximum anticipated static and dynamic inclination angles as well as maximum anticipated acceleration values, to prevent displacement of hydrogen storage units.

5.3.1.3 Hydrogen storage units shall be protected against mechanical damage.

5.3.1.4 Connecting piping associated with hydrogen storage units shall be provided with sufficient flexible compensation.

5.3.2 Design

5.3.2.1 General Requirements

Design of hydrogen storage units shall comply with Rules for Classification of Sea-Going Steel Ships or Rules for Construction of Steel Inland Waterway Ships, as well as Rules for Materials and Welding.5.3.2.2 Design Strength

Design of hydrogen storage vessel shall take account of stress level under 1.5 times maximum developed pressure (MDP). Influences upon stress level of each component under maximum developed pressure shall be considered, including but not limited to:

— 1.5 × maximum developed pressure (MDP);

— thermal-stress including different ratios of thermal expansion and contraction;

— weight of internal components inside metal-hydride hydrogen storage vessel in any possible direction;

— impact and vibration loads;

— maximum stress induced by expansion of hydrogen-absorbing alloy;

— other mechanical loads.

5.3.2.3 Other Requirements

(1) Hydrogen storage unit shall prevent local accumulation of solid filling materials during service.

(2) Filters with filtration accuracy matching particle size of solid-state hydrogen-storage substances shall be fitted at ports of each single hydrogen storage vessel or vessel bank. Possibility of pulverization of solid-state hydrogen-storage substances shall also be taken into consideration.

(3) For hydrogen storage vessels realizing hydrogen absorption-desorption assisted by thermal effect, heat-exchanger-type structure shall preferably be adopted according to hydrogen-storage capacity and magnitude of thermal effect of solid-state hydrogen-storage substances.

5.3.3 Performance and Safety Requirements

5.3.3.1 Materials of hydrogen storage vessel in contact with fuel shall be hydrogen-compatible, and influence of hydrogen embrittlement upon service life shall be considered.

5.3.3.2 Devices or measures shall be provided to limit leakage rate in case of accidental disconnection or rupture of connecting joints of hydrogen storage vessel.

5.3.3.3 Design of hydrogen storage vessel and hydrogen supply piping shall ensure that safety actions taken after leakage shall not result in unacceptable losses.

5.3.3.4 Design and construction of hydrogen storage vessel shall prevent leakage of hydrogen gas or metal hydride during normal system operation.

5.3.3.5 Minimum quality requirement of hydrogen filled into hydrogen storage vessel shall be clearly specified by manufacturer of hydrogen storage unit in accordance with ISO 14687. Where hydrogen quality constitutes key factor for performance of hydrogen storage vessel, manufacturer may specify hydrogen quality requirement on product nameplate.

5.3.4 Supplementary Requirements for Titanium-Based Metal-Hydride Hydrogen Storage Units

In addition to requirements specified in 5.3.1 to 5.3.3, hydrogen storage units adopting titanium-based metal hydride shall also satisfy the following requirements:5.3.4.1

As-cast alloy shall preferably be subjected to homogenizing annealing treatment.

5.3.4.2 Tolerance for main element ratio and limit for composition segregation of each batch shall be specified, and P-C-T report shall be provided for each batch.

5.3.4.3 Filling and encapsulation of hydrogen storage unit shall preferably adopt the mode of filling first followed by in-situ activation.

5.3.4.4 Purity of raw hydrogen shall be no lower than technical requirements specified by manufacturer. Purification device shall preferably be fitted at outlet of bunkering system, and on-line monitoring measures for purity and impurities shall be provided.

5.3.5 Supplementary Requirements for Vanadium-Based Metal-Hydride Hydrogen Storage Units

In addition to requirements specified in 5.3.1 to 5.3.3, hydrogen storage units adopting vanadium-based metal hydride shall also satisfy the following requirements:

5.3.5.1 Heat-exchange structure shall take account of influence of heat-release rate during hydrogen absorption-desorption to avoid local over-heating caused by concentrated heat release.

5.3.5.2 Vanadium-based material shall be subjected to high-temperature homogenizing heat treatment.

5.3.5.3 Design of hydrogen storage unit shall take account of expansion of hydrogen-storage bed assembly along crystal lattice orientation during activation and hydrogen absorption-desorption cycles.

5.3.5.4 Multi-point temperature monitoring shall be provided for hydrogen-storage bed assembly. Arrangement of temperature-monitoring measuring points shall be assessed according to design of hydrogen storage unit.

5.4 Hydrogen Supply System

5.4.1 Piping and valves in contact with hydrogen inside hydrogen supply system shall possess good hydrogen compatibility and shall operate stably over long-term period under hydrogen service conditions.

5.4.2 Design of piping for hydrogen supply system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.4.3 Inerting of hydrogen supply system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel and Guidelines for Hydrogen Bunkering Operations on Ships.

5.4.4 Hydrogen supply system shall be provided with function for manual emergency shut-off of hydrogen supply.

5.4.5 Hydrogen-gas detection-alarm devices shall be arranged at positions prone to accumulation of hydrogen inside hydrogen supply system. The system shall be so arranged that failure of a single hydrogen detector shall not impair normal operation of hydrogen-gas detection-alarm devices.

5.4.6 The hydrogen supply system shall be properly earthed. Good contact without loosening shall be maintained among earthing device, earthing conductor, earthing wire and earthing point. The static-electricity earthing shall preferably share common earth electrode with other earthing circuits. If dedicated static-electricity earthing is adopted, earthing resistance shall be no more than 10 Ω. Flange joints on hydrogen piping shall be bonded with metal jumpers, and bonding resistance shall be less than 0.03 Ω.

5.5 Bunkering System

5.5.1 Piping and valves in contact with hydrogen inside bunkering system shall possess good hydrogen compatibility and shall operate stably over long-term period under hydrogen service conditions.

5.5.2 Design of piping for bunkering system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.5.3 Inerting of bunkering system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel and Guidelines for Hydrogen Bunkering Operations on Ships.

5.5.4 Temperature-regulating devices shall be provided according to pressure grade and service requirements. Heat-exchange circulating medium shall be circulated into marine solid-state hydrogen storage, supply and bunkering system via piping to absorb reaction heat generated during hydrogen absorption by solid-state hydrogen-storage

materials. Leakage of heat-exchange circulating medium shall not exert adverse impact upon hydrogen storage-supply system and bunkering system. Closed-loop control shall be adopted for hydrogen-charging flow rate of hydrogen storage system adopting vanadium-based metal hydride.

5.5.5 Ship-board bunkering system shall support real-time communication with shore-side bunkering system. In case of communication interruption, hydrogen bunkering shall be stopped or switched to non-communication-mode bunkering under safe conditions.

5.5.6 Bunkering system shall be provided with function for manual emergency shut-off of bunkering operation.

5.5.7 Hydrogen-gas detection-alarm devices shall be arranged at positions prone to accumulation of hydrogen inside bunkering system. The system shall be so arranged that failure of a single hydrogen detector shall not impair normal operation of hydrogen-gas detection-alarm devices.

5.5.8 The bunkering system shall be properly earthed. Good contact without loosening shall be maintained among earthing device, earthing conductor, earthing wire and earthing point. The static-electricity earthing shall preferably share common earth electrode with other earthing circuits. If dedicated static-electricity earthing is adopted, earthing resistance shall be no more than 10 Ω. Flange joints on hydrogen piping shall be bonded with metal jumpers, and bonding resistance shall be less than 0.03 Ω.

5.6 Control, Monitoring and Safety System

The control, monitoring and safety system of hydrogen storage, supply and bunkering system shall realize alarm and safety functions specified in Table 12.4.1 of Guidelines for Ships Using Hydrogen Fuel. Remote display of alarm information as well as acoustic-visual alarm shall be available.

In case of system failures specified in Table 12.4.1 of Guidelines for Ships Using Hydrogen Fuel and other failures developing too rapidly for manual intervention, the safety system shall automatically shut-off fuel supply system.

5.6.1 Installation Requirements

5.6.1.1 Suitable instrument devices shall be provided for local and remote indication of

important parameters of hydrogen storage, supply and bunkering system, so as to ensure safety management of all fuel equipment and bunkering operations.

5.6.1.2 Local pressure indicator shall be fitted to indicate pressure between ship-board system stop valve and hose ship-shore coupling.

5.6.1.3 At least one locally-readable pressure gauge shall be fitted on each main hydrogen manifold.

5.6.1.4 Each hydrogen storage vessel shall be fitted with local pressure gauge clearly marked with maximum permissible pressure and minimum permissible pressure for hydrogen storage vessel. Pressure indication shall also be provided at remote positions (e.g. wheelhouse, machinery-space control room or ship safety centre, etc.). In addition, high-pressure and low-pressure alarms shall be provided at manned spaces, and acoustic-visual alarm shall be triggered when preset maximum / minimum pressure values are reached.

5.6.1.5 Hydrogen storage vessel shall be fitted with pressure sensor. Acoustic-visual alarm shall be triggered when internal pressure of vessel reaches preset alarm value (high pressure or low pressure). Fuel output shall be cut-off in a timely manner when pressure drops below minimum pressure required for safe operation of hydrogen-consuming equipment.

5.6.2 Function and Safety Requirements

5.6.2.1 Abnormal pressure / temperature associated with equipment of hydrogen storage, supply and bunkering system shall be monitored, and acoustic-visual alarm shall be triggered when limit values are exceeded.

5.6.2.2 Gas-leakage conditions of hydrogen storage, supply and bunkering system shall be monitored, and acoustic-visual alarm shall be triggered when limit values are exceeded.

5.6.2.3 For electrical equipment involved in hydrogen storage, supply and bunkering system which shall adopt qualified explosion-proof equipment according to hazardous-area classification requirements, its explosion-proof category shall be no lower than IIC or IIB+H2, and temperature class shall be no lower than T1.

6 Raw Materials and Components

Raw materials and components of products shall be controlled in accordance with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

7 Type Test

Type test shall be carried out for hydrogen storage unit in accordance with requirements of this Clause. For marine solid-state hydrogen storage, supply and bunkering system, piece / batch survey shall be performed in accordance with approved drawings in conjunction with ship-board projects.

7.1 Selection of Representative Sample

7.1.1 Type test shall be performed for each type of hydrogen storage unit. Hydrogen storage units shall be regarded as of different types in case any of the following conditions applies:

(1) Different design pressure;

(2) Different wall thickness;

(3) Different material grade;

(4) Different type of metal hydride;

(5) Different welding procedure for hydrogen storage vessel.

7.1.2 The hydrogen storage unit taken as sample for type test shall be subject to surveyor’s on-site supervision from raw-material acceptance, main manufacturing processes, inspection and test, to relevant marking transfer. The results shall satisfy requirements of Rules for Classification of Sea-Going Steel Ships and approved drawings.

7.2 Type-test Items and Requirements

7.2.1 Type-test items and requirements for hydrogen storage unitType Test Items for Hydrogen Storage Unit with Seamless Hydrogen Storage Container (≤150 L) Table 7.2.1.1

No.	Test Item	Technical Requirements and Test Methods
1.	Fire 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 Cycling and Strain Measurement Test	ISO 16111:6.2.6
5.	Shut-off Valve Impact Test	ISO 16111:6.2.7
6.	Temperature Cycling Test	ISO 16111:6.2.8
7.	Maximum Temperature Rise Pressure Test	ISO 16111:6.3.3
8.	Burst Test	ISO 16111:6.3.2

Type Test Items for Hydrogen Storage Unit with Welded Hydrogen Storage Container Table 7.2.1.2

No.	Test Item	Technical Requirements and Test Methods
1.	Hydrostatic Test of Hydrogen Storage Container	7.2.1.1
2.	Visual and Structural Inspection	7.2.1.2
3.	Fire Test	7.2.1.3
4.	Leakage Test (Tightness Test)	7.2.1.4
5.	Temperature Cycling Test	7.2.1.5

6.	Hydrogen Discharge Performance Test	7.2.1.6
7.	Hydrogen Filling Performance Test	7.2.1.7
8.	Maximum Temperature Rise Pressure Test	7.2.1.8
9.	Cyclic Hydrogen Filling/Discharging Life Test	7.2.1.9

Note: 1. For fire test, temperature cycling test and cyclic hydrogen charging / desorption life test, scaled-down hydrogen storage unit may be adopted for alternative test. The scaling-down principle formulated by manufacturer shall be subject to CCS approval.

7.2.1.1 Hydrostatic Test of Hydrogen Storage Vessel

Hydrostatic test for hydrogen storage vessel shall be performed in accordance with Rules for Classification of Sea-Going Steel Ships. The test pressure shall be 1.5 times maximum developed pressure (MDP). Pressure shall be held for at least 30 min under test pressure, with no pressure drop, no leakage and no obvious deformation. Elastic expansion shall be less than ultimate expansion, and residual volumetric deformation rate after pressure relief shall be no more than 5 %.7.2.1.2 Visual and Structural Inspection

During visual and structural inspection, unit appearance, marking, interfaces and structure shall be checked to satisfy the following requirements:

(1) Outer surface shall be clean and free of mechanical damage; contact points of interfaces shall be free of rust; burrs, welding slags, rust and dirt shall be removed from hydrogen-contact surfaces;

(2) Product nameplate shall be clearly legible;

(3) Clear marking shall be provided for hydrogen charging / desorption interfaces and heat-exchange medium interfaces.

7.2.1.3 Fire Test

1. Test Requirements

a) Three hydrogen storage units shall be subjected to fire test respectively in horizontal, vertical and another arbitrary orientation.

b) Fire test shall be carried out in well-ventilated indoor space or spacious outdoor site with necessary protection to guarantee safety of test personnel.

c) Fuel shall provide uniform heat release and sustain combustion for at least 20 min under specified test conditions, and shall comply with environmental-protection requirements.

d) An additional remote over-pressure relief device shall be fitted on hydrogen storage unit to realize timely pressure relief in case of failure of its built-in over-pressure relief device.

e) During fire test of hydrogen storage unit, over-pressure relief device shall operate normally; the hydrogen storage unit shall not rupture and no projectile shall be generated.

2. Test Procedures

a) Before test, fill hydrogen storage unit with hydrogen up to rated charging pressure in accordance with manufacturer’s specified method.

b) Thermocouples shall be placed within 0.05 m from unit surface without direct contact with the surface.

c) In test orientation, place hydrogen storage unit at least 0.1 m or higher above fuel to ensure full enclosure by flame; protect accessories such as shut-off valves and over-pressure relief devices against direct flame impingement.

d) Record details of fuel source, low-pressure hydrogen storage unit and measuring-instrument layout, then start fire test.

e) Thermocouple temperature shall be maintained within 500 ℃～550 ℃ during test.

f) Remotely monitor and record temperature and pressure signals of hydrogen storage unit, with data-recording interval no more than 15 s. Besides temperature and pressure readings, record the following information for each test:

— Manufacturer and model of metal-hydride hydrogen storage unit;

— Type and actuation pressure (temperature) of over-pressure relief device;

— Placement orientation of hydrogen storage unit;

— Position and orientation of over-pressure relief device;

— Rated charging pressure of hydrogen storage unit and completed hydrogen-charging-desorption cycles;

— Actuation time of over-pressure relief device and total test duration;

— Ambient temperature;

— Wind force / wind direction;

— Test personnel;

— Test date.

7.2.1.4 Leakage Test (Tightness Test)

1. Test Requirements

(1) Nitrogen-helium mixed gas shall be adopted for tightness test; volume fraction of helium in mixed gas shall be no less than 10 %. Exact helium content shall be determined by test to guarantee test accuracy.

(2) Leakage rate of nitrogen-helium mixed gas shall be converted into equivalent hydrogen leakage rate. Under standard conditions (0 ℃, 101.325 kPa), total hydrogen leakage rate of hydrogen storage unit shall be less than 6 Ncm^3/h.

2. Test Procedures

(1) Fill hydrogen storage unit with nitrogen-helium mixed gas up to maximum developed pressure (MDP);

(2) Place hydrogen storage unit inside closed chamber. Connect closed chamber with gas-detecting instrument (e.g. helium mass spectrometer, quadrupole mass

spectrometer, gas chromatograph, etc.), then evacuate the vacuum chamber until vacuum degree is lower than 2 Pa.

(3) Let hydrogen storage unit stand for more than 30 min at room temperature, then read vacuum-degree and leakage-rate data from gas-detecting instrument.

Note: Before placing hydrogen storage unit into closed-chamber for tightness test, dedicated leak-detection-liquid method shall be applied to check for obvious leakage points at all potential leakage locations.

7.2.1.5 Temperature Cycling Test1. Test Requirements

a) Temperature range for temperature cycling test of hydrogen storage unit shall be no less than its operating ambient-temperature range.

b) For hydrogen storage units with specified transportation and service orientation, no less than three units shall be tested under specified orientations.

c) Fill hydrogen storage unit with hydrogen up to rated filling capacity in specified manner, then place into test chamber.

d) Test chamber shall be equipped with temperature-control device to guarantee uniform internal temperature. The chamber shall be capable of rising from minimum operating ambient temperature to maximum operating ambient temperature within 120 min and vice versa.

e) Upon completion of temperature cycling test, tightness test shall be performed in accordance with 7.2.1.4 and shall satisfy requirements of 7.2.1.4.2. Test Procedures

Place hydrogen-filled hydrogen storage unit into test chamber and perform temperature cycling test in accordance with the following steps (see Figure 1):

a) Raise chamber temperature from room temperature to maximum ambient temperature within (60 ± 5) min;

b) Maintain hydrogen-storage-unit temperature at maximum ambient temperature for at least 60 min, with temperature tolerance ±2 ℃;

c) Lower chamber temperature from maximum ambient temperature down to

minimum ambient temperature within (120 ± 5) min;

d) Maintain hydrogen-storage-unit temperature at minimum ambient temperature for at least 60 min, with temperature tolerance ±2 ℃;

e) Raise chamber temperature back to room temperature within (60 ± 5) min;

f) Repeat steps a) to e) for 50 cycles.

g) Perform tightness test in accordance with 7.2.1.4 after temperature cycling test.

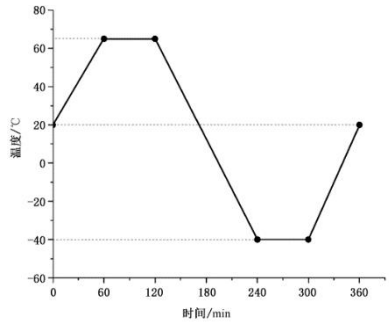

Fig. 1 Temperature variation during temperature cycling test

Note: Take maximum ambient temperature 65 ℃ and minimum ambient temperature −40 ℃ as example for Figure 1 temperature profile.

Note: For hydrogen storage systems adopting magnesium-based metal hydride, additional thermal-cycling test shall be performed: raise system temperature up to 350 ℃ (±10 ℃) within 10 h and hold for at least 1 h; cool down to 50 ℃ (±10 ℃) within 8 h and hold for at least 1 h. Upon completion of thermal-cycling test, tightness test shall be performed in accordance with 7.2.1.4.

7.2.1.6 Hydrogen Desorption Performance Test1. Test Requirements

No less than three hydrogen storage units of identical specification shall be tested. No less than two repeated tests shall be carried out under identical working conditions and average value shall be adopted.

a) Negative deviation of measured hydrogen-desorption quantity of hydrogen storage unit from nominal rated filling capacity shall be no greater than 5 %.

b) Measured hydrogen purity of desorbed hydrogen shall satisfy manufacturer’s

specifications.

c) Calculated gravimetric hydrogen-storage density and volumetric hydrogen-storage density of hydrogen storage unit shall satisfy manufacturer’s specifications.2. Test Procedures

a) Fix pre-hydrogen-filled test unit on test bench, connect gas circuit, perform tightness check to ensure no hydrogen leakage in test gas circuit; fit thermocouples for measurement.

b) Set instrument flow-control value according to nominal hydrogen-desorption rate of test unit.

c) Start test instrument, open shut-off valve of hydrogen storage unit; simultaneously measure and record hydrogen-desorption pressure, hydrogen-desorption temperature (vessel surface temperature), flow rate, total desorbed-hydrogen quantity and desorption duration.

d) Determine hydrogen purity of desorbed hydrogen in accordance with test methods specified in GB/T 3634.2.

e) Weigh test hydrogen storage unit. Calculate gravimetric hydrogen-storage density and volumetric hydrogen-storage density of hydrogen storage unit according to measured hydrogen-storage capacity and unit mass.7.2.1.7 Hydrogen Charging Performance Test1. Test Requirements

No less than three hydrogen storage units of identical specification shall be tested. No less than two repeated tests shall be carried out under identical working conditions and average value shall be adopted.

Negative deviation of measured hydrogen-charging quantity of hydrogen storage unit from nominal rated filling capacity shall be no greater than 5 %.

Hydrogen-charging rate of hydrogen storage unit shall satisfy manufacturer’s specifications.2. Test Procedures

a) Fix test hydrogen storage unit on test bench, connect gas circuit, evacuate to eliminate residual impurity gas inside hydrogen storage vessel and perform tightness check to ensure no leakage of test gas circuit; fit thermocouples for measurement.

b) Hydrogen-charging-gas purity shall satisfy manufacturer’s specifications.

c) Set charging-pressure control value in accordance with nominal charging pressure of test unit; nominal charging pressure shall comply with manufacturer’s specifications.

d) Start test instrument, open shut-off valve of hydrogen storage vessel and commence hydrogen charging; simultaneously measure and record hydrogen-charging pressure, hydrogen-charging temperature, flow rate, total charged-hydrogen quantity and charging duration.

e) Fill hydrogen storage unit up to rated capacity. Calculate hydrogen-charging rate according to measured charging duration and charged-hydrogen capacity.7.2.1.8 Maximum Developed Pressure Test

Maximum developed pressure (MDP) shall be determined by manufacturer according to temperature-pressure characteristics of metal hydride.Under normal service conditions, test the maximum gauge gas pressure reached at equilibrium when hydrogen storage unit is filled up to nominal capacity, and take the larger value for verification of maximum developed pressure. Under any circumstances, tested maximum developed pressure shall not exceed 0.80 times hydrostatic-test pressure of hydrogen storage vessel.

7.2.1.9 Cyclic Hydrogen Charging / Desorption Life Test1. Test Requirements

Cyclic hydrogen-charging-desorption life of hydrogen storage unit shall be no less than 2000 cycles. After completion of 2000 charging-desorption cycles, hydrogen-storage capacity of system shall be no less than 85 % of nominal hydrogen-storage capacity.2. Test Methods

a) Desorb hydrogen from hydrogen storage unit at temperature no higher than 45 ℃ with hydrogen-desorption rate no less than nominal hydrogen-desorption rate down to 80 % of nominal hydrogen-storage capacity; hold for 1 h.

b) Charge hydrogen into hydrogen storage unit at temperature no higher than 45 ℃ and under nominal charging-pressure condition with hydrogen-charging rate no less than nominal hydrogen-charging rate up to 80 % of nominal hydrogen-storage capacity; one complete charging-desorption cycle is finished.

c) Repeat steps a)-b) continuously for 24 cycles.

d) Every 25 cycles constitute one test period. After completion of 24-th cycle, perform 25-th cycle: charge hydrogen up to 105 % of nominal hydrogen-storage capacity (i.e. 5 % over-charge of nominal hydrogen-storage capacity). If hydrogen-desorption capacity measured in 25-th cycle of any period is less than 85 % of nominal hydrogen-storage capacity, terminate cyclic-life test.

Note: Test may also be performed for metal hydride in accordance with methods specified in GB/T 33291; test results shall satisfy requirements of this Clause.

7.3 Electrical and electronic equipment within control, monitoring and safety system of hydrogen storage, supply and bunkering system shall also be tested in accordance with relevant requirements of Guidelines for Type Approval Test of Electrical and Electronic Products.

8 Piece / Batch Survey

8.1 Hydrogen Storage Vessel

Batch quantity shall be determined by manufacturer according to capacity and constituent materials of metal-hydride hydrogen-storage device. Two types of batch quantities shall be considered:

(1) Batch quantity of metal hydride shall be determined by batch of hydrogen-absorbing metal or subject to CCS agreement.

(2) Batch quantity of hydrogen storage vessel shall be determined by batch definition given in relevant standards for hydrogen-storage vessels or subject to CCS agreement.8.1.1 Leakage Test

As part of routine test, each finished hydrogen storage vessel shall be subjected to leakage test at room temperature and rated charging pressure (RCP), and shall satisfy acceptance criteria.8.1.2 Burst Test (Applicable to seamless hydrogen-storage vessels)At least one hydrogen-storage-vessel shell shall be selected from each batch for pressure burst test. For hydrogen-storage vessels with internal volume greater than 120 mL, test method and acceptance criteria for burst test shall comply with standards adopted for vessel design.8.2 Hydrogen Storage Unit

The following factory-inspection items shall be performed for hydrogen storage unit:

(1) Visual and structural inspection

(2) Hydrostatic test of hydrogen storage vessel

(3) Leakage Test (Tightness Test)

(4) Temperature Cycling Test

(5) Hydrogen Desorption Performance Test8.3 Hydrogen Storage System8.3.1 Visual and Structural Inspection

During visual and structural inspection of system, system appearance, marking and interfaces shall be checked to satisfy the following requirements:

(1) Outer surface shall be clean and free of mechanical damage; contact points of interfaces shall be free of rust; burrs, welding slags, rust and dirt shall be removed from hydrogen-contact surfaces;

(2) Product nameplate shall be clearly legible;

(3) Clear marking shall be provided for hydrogen charging / desorption interfaces and heat-exchange medium interfaces.8.3.2 Tightness Test

Nitrogen-helium mixed gas shall be adopted for tightness test; volume fraction of helium in mixed gas shall be no less than 10 %. Exact helium content shall be determined by test to guarantee test accuracy. Leakage rate of nitrogen-helium mixed gas shall be converted into equivalent hydrogen leakage rate. Fill hydrogen storage system with nitrogen-helium mixed gas up to maximum developed pressure (MDP). Place hydrogen storage system inside closed chamber. Connect closed chamber with gas-detecting instrument (e.g. helium mass spectrometer, quadrupole mass spectrometer, gas chromatograph, etc.), then evacuate vacuum chamber until vacuum degree is lower than 2 Pa. Let hydrogen storage system stand for more than 30 min at room temperature, then read vacuum-degree and leakage-rate data from gas-detecting instrument.

Note: Before placing hydrogen storage system into closed-chamber for tightness test, dedicated leak-detection-liquid method shall be applied to check for obvious leakage

points at all potential leakage locations.

8.3.3 Over-pressure Safety Performance Test

Raise hydrogen pressure of hydrogen storage system above actuation pressure of relief device provided by manufacturer, and check normal operation of relief device. Actuation pressure of pressure relief valve shall be lower than 0.8 times maximum allowable pressure of hydrogen-storage vessel, valves, joints and hydrogen piping, and shall be no greater than 1.5 times rated charging pressure of system.

8.3.4 Hydrogen Desorption Performance Test

1. Test Requirements

No less than three hydrogen storage systems of identical specification shall be tested. No less than two repeated tests shall be carried out under identical working conditions and average value shall be adopted.

a) Negative deviation of measured hydrogen-desorption quantity of hydrogen storage system from nominal rated filling capacity shall be no greater than 5 %.

b) Measured hydrogen purity of desorbed hydrogen shall satisfy manufacturer’s specifications.

c) Calculated gravimetric hydrogen-storage density and volumetric hydrogen-storage density of hydrogen storage system shall satisfy manufacturer’s specifications.

2. Test Procedures

a) Fix pre-hydrogen-filled test hydrogen-storage system on test bench, connect gas circuit, perform tightness check to ensure no hydrogen leakage in test gas circuit; fit thermocouples for measurement.

b) Set instrument flow-control value according to nominal hydrogen-desorption rate of test system.

c) Start test instrument, open shut-off valve of hydrogen storage unit; simultaneously measure and record hydrogen-desorption pressure, hydrogen-desorption temperature (vessel surface temperature), flow rate, total desorbed-hydrogen quantity and

desorption duration.

d) Determine hydrogen purity of desorbed hydrogen in accordance with test methods specified in GB/T 3634.2.

e) Weigh test hydrogen-storage system. Calculate gravimetric hydrogen-storage density and volumetric hydrogen-storage density of hydrogen-storage system according to measured hydrogen-storage capacity and system mass.

8.3.5 Hydrogen Charging Performance Test

1. Test Requirements

No less than three hydrogen storage systems of identical specification shall be tested. No less than two repeated tests shall be carried out under identical working conditions and average value shall be adopted.

Negative deviation of measured hydrogen-charging quantity of hydrogen storage system from nominal rated filling capacity shall be no greater than 5 %.

Hydrogen-charging rate of hydrogen storage system shall satisfy manufacturer’s specifications.

2. Test Procedures

a) Fix test hydrogen-storage system on test bench, connect gas circuit, evacuate to eliminate residual impurity gas inside hydrogen-storage vessel and perform tightness check to ensure no leakage of test gas circuit; fit thermocouples for measurement.

b) Hydrogen-charging-gas purity shall satisfy manufacturer’s specifications.

c) Set charging-pressure control value in accordance with nominal charging pressure of test system; nominal charging pressure shall comply with manufacturer’s specifications.

d) Start test instrument, open shut-off valve of hydrogen-storage vessel and commence hydrogen charging; simultaneously measure and record hydrogen-charging pressure, hydrogen-charging temperature, flow rate, total charged-hydrogen quantity and charging duration.

e) Fill hydrogen-storage system up to rated capacity. Calculate hydrogen-charging rate

according to measured charging duration and charged-hydrogen capacity.

8.4 Hydrogen Supply and Bunkering System

8.4.1 Visual and Structural Inspection

Visual inspection and routine review of design drawings and specifications shall be performed to verify conformity between actual fabrication and approved drawings.

8.4.2 Pressure-resistance Test

Nitrogen shall be adopted as test medium for pressure-resistance test of piping of hydrogen supply and bunkering system.

Connect piping of hydrogen supply system to gas source, replace safety valve with blanking plug, gradually raise pressure up to 1.5 times design pressure and hold for 30 min. The test is acceptable if no leakage, visible deformation or abnormal noise occurs during pressure holding.

Connect inlet of bunkering-system piping to gas source, replace safety valve with blanking plug, gradually raise pressure up to 1.5 times design pressure and hold for 30 min. The test is acceptable if no leakage, visible deformation or abnormal noise occurs during pressure holding.

8.4.3 Tightness Test

Nitrogen shall be adopted as test medium for tightness test of hydrogen supply and bunkering system.

For hydrogen supply system: connect outlet to gas source, replace safety valve with blanking plug. Raise pressure step-by-step by 1 MPa increments and hold for 15 min at each pressure step. Apply dedicated leak-detection liquid to full piping system; after confirming no visible bubble, raise pressure step-by-step up to maximum working pressure and hold for 12 h. After temperature correction, pressure drop during test shall not exceed 1 % of test pressure and shall not exceed 0.05 MPa.

For bunkering system: connect inlet to gas source, replace safety valve with blanking plug. Raise pressure step-by-step by 1 MPa increments and hold for 15 min at each pressure step. Apply dedicated leak-detection liquid to full piping system; after

confirming no visible bubble, raise pressure step-by-step up to maximum working pressure and hold for 12 h. After temperature correction, pressure drop during test shall not exceed 1 % of test pressure and shall not exceed 0.05 MPa.

8.4.4 Function Test

Verify that hydrogen supply system fulfils functions specified in Clause 5.4, bunkering system fulfils functions specified in Clause 5.5, and control-monitoring-safety system fulfils functions specified in Clause 5.6.

Part 3

Marine High-Pressure Hydrogen Storage, Supply and Bunkering System

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1 Scope of Application

1.1 This Guideline applies to marine high-pressure hydrogen storage, supply and bunkering system. Such system consists of hydrogen storage device, hydrogen supply system, bunkering system, as well as control, monitoring and safety system.

1.2 For hydrogen cylinders in hydrogen storage device, the nominal working pressure for storage design and manufacture shall be 35 MPa and 70 MPa, with nominal volume not less than 20 L and not greater than 450 L, and operating temperature ranging from −40 ℃ to 85 ℃. Hydrogen cylinders are divided into Class-A cylinders and Class-B cylinders. The nominal working pressure of Class-A cylinder is 35 MPa, and that of Class-B cylinder is 70 MPa.

1.3 It is applicable to hydrogen-fuel-powered ships using hydrogen as fuel.

2 Normative References

Provisions of the referenced documents shall constitute provisions of this Guideline by reference herein. For undated references, the latest edition shall apply.

2.1 China Classification Society, Rules for Classification of Sea-Going Steel Ships

2.2 China Classification Society, Rules for Construction of Steel Inland Waterway Ships

2.3 China Classification Society, Rules for Materials and Welding

2.4 China Classification Society, Guidelines for Ships Using Hydrogen Fuel

2.5 China Classification Society, Guidelines for Type Approval Test of Electrical and Electronic Products

2.6 GB/T 35544-2025, Fully-wound carbon fiber composite cylinders with aluminium liner for compressed hydrogen for vehicles

2.7 GB/T 42612-2023, Fully-wound carbon fiber composite cylinders with plastic liner for compressed hydrogen for vehicles

2.8 GB/T 3362-2017, Test method for tensile properties of carbon fiber multifilament

2.9 GB/T 13005-2011, Terminology for gas cylinders

2.10 GB/T 29729-2022, Basic safety requirements for hydrogen systems

2.11 GB/T 3634.2-2025, Hydrogen — Part 2: Pure hydrogen, high-purity hydrogen and ultra-high-purity hydrogen

2.12 TSG 23-2021, Safety Technical Specification for Gas Cylinders

3 Terms and Definitions

The terms and definitions specified in the above-mentioned normative references shall apply to this Guideline. For convenience of compilation and application, the following definitions are cited and supplemented herein.

3.1 For definitions of terms such as product survey, approval, type test, sample, piece / batch survey, refer to 3.1.2, Chapter 3, Part 1 of Rules for Classification of Sea-Going Steel Ships.

3.2 Aluminium liner: Seamless aluminium-alloy container with carbon-fiber-reinforced layer wound on outer surface, for gas sealing, which may or may not bear partial pressure load.

3.3 Plastic liner: Inner plastic shell with externally wound carbon-fiber-reinforced layer, designed not to bear pressure load for gas sealing.

3.4 Full-winding: Winding mode in which resin-impregnated carbon fiber is continuously wound over liner in hoop and helical directions to enhance circumferential and axial strength of hydrogen cylinder.

3.5 Fully-wound hydrogen cylinder: Hydrogen cylinder formed by full-winding over liner followed by heat curing.

3.6 Autofrettage: Pressurization process by applying internal pressure to hydrogen cylinder to induce plastic deformation of aluminium liner, so that aluminium liner bears compressive stress and carbon fiber bears tensile stress under zero internal pressure.

3.7 Autofrettage pressure: Maximum gauge internal pressure applied to hydrogen cylinder during autofrettage process.

3.8 Design service life of hydrogen cylinder: Permissible service years of hydrogen cylinder under specified service conditions.

3.9 Fiber stress ratio: Ratio of carbon-fiber stress at minimum design burst pressure to carbon-fiber stress at nominal working pressure for hydrogen cylinder.

3.10 Ultimate elastic expansion volume: Allowable upper-limit value of elastic expansion volume of hydrogen cylinder specified by manufacturer at design-finalization stage for each type and size, in millilitres. Such value shall not exceed 1.1 times the average elastic expansion volume of hydrogen cylinders of identical type and size from design-finalization batch under hydrostatic test pressure.

3.11 Hydrogen storage device: Consisting of hydrogen cylinders, cylinder-neck combined valve, pressure relief devices and connecting piping, for safe storage of hydrogen inside hydrogen cylinders.

3.12 Hydrogen supply system: Mainly consisting of relevant valves, connecting piping, instruments and control system, which supplies clean hydrogen gas at applicable pressure and flow rate to hydrogen-consuming equipment in a safe manner.

3.13 Bunkering system: Consisting of bunkering coupling, vapour-return coupling (if fitted), relevant valves, connecting piping, instruments and control system, for hydrogen bunkering into hydrogen cylinders.

4 Drawings and Documents

4.1 The following drawings and documents shall be submitted to CCS for review:

4.1.1 Hydrogen Storage and Supply System

(1) System flow diagram;

(2) Product technical specification and main product performance data sheet;

(3) Detailed parameters, drawings and list of physical and chemical properties for piping system, including pressure relief piping and vent piping, etc.;

(4) Strength calculation document for piping and pipe fittings, calculation document for safety and over-pressure relief capacity;

(5) Drawings and descriptions for flanges, valves and other devices;

(6) Relevant process documents for piping system, including but not limited to welding and non-destructive-testing;

(7) Technical documents for piping pressure test (strength test and tightness test);

(8) Drawing and layout drawing of monitoring and alarm system, including layout drawing of monitoring probes, sensors, alarm devices and alarm points, as well as set-values for alarm and control;

(9) Schematic diagram, component list, software functional block diagram, list of alarm types and list of safety-action types for control equipment (including control, monitoring and safety system);

(10) Performance-test program for hydrogen storage and supply system, including function verification for valves, accessories and operation-related equipment;

(11) External piping connection drawing;

(12) Whole-service-life performance description for hydrogen storage and supply system (performance variation over service life);

(13) Failure Mode and Effects Analysis (FMEA) report for hydrogen storage, supply and bunkering system;

(14) Stress-analysis report for hydrogen storage and supply piping and bunkering piping;

(15) System specification or operation manual;

(16) Nameplate drawing;

(17) List of necessary auxiliary equipment (if any);

(18) Where survey is carried out on a project basis, relevant requirements of approved ship drawings shall also be verified.

4.1.2 Hydrogen Cylinders

(1) Main product performance data sheet;

(2) General assembly drawing and main component drawings;

(3) Strength calculation document and pressure relief device calculation document;

(4) List of physical and chemical properties for main pressure-bearing components;

(6) Stress-analysis report (where applicable);

(7) Manufacturing process documents.

4.1.3 Bunkering System

(1) General layout drawing of bunkering system;

(2) Drawings of main components: piping and accessories, valves, bunkering port, etc.;

(3) List of physical and chemical properties for main pressure-bearing components: piping, valves, etc.;

(4) Design calculation document: calculation of safe and over-pressure relief capacity, structural-strength calculation for piping;

(5) Drawing and layout drawing of monitoring and alarm system, including layout drawing of monitoring probes, sensors, alarm devices and alarm points, as well as set-values for alarm and control;

(6) Schematic diagram, component list, software functional block diagram, list of alarm types and list of safety-action types for control equipment (including control, monitoring and safety system)

(7) Risk-analysis report;

(8) Product-performance specification sheet.

4.2 The following documents shall additionally be submitted when applying for approval of hydrogen cylinders:

(1) Brief introduction of the enterprise, technical characteristics (if any) or basic description of products to be approved;

(2) Simplified process flow of products;

(3) List of main production, inspection and test equipment for products;

(4) Other valid documents, reports and certificates demonstrating the Client's production capacity and quality level for products within the scope of approval;

(5) Enterprise-registration certificate or business license, quality-system certificate or document, qualification certificate and/or production license (if any);

(6) List of suppliers for main raw materials and components (where necessary);

(7) Sample of product certificate of quality;

(8) Key manufacturing-process documents or document list of products;

(9) Approval-test program.

5 Technical Requirements

5.1 General Requirements

5.1.1 Structural design, strength calculation, manufacturing process, arrangement of piping and accessories, system safety and protection of marine high-pressure hydrogen storage, supply and bunkering system shall comply with Guidelines for Ships Using Hydrogen Fuel and standards accepted by CCS.

5.1.2 Welding-procedure qualification

For piping of welded construction, welding-procedure qualification shall be performed under supervision of CCS surveyor.

5.2 System Design

5.2.1 Risk control for design of hydrogen storage, supply and bunkering system shall comply with Clause 7.2 of GB/T 29729.

5.2.2 The hydrogen storage, supply and bunkering system shall preferably adopt modular structure convenient for assembly, inspection and maintenance.

5.2.3 The hydrogen storage, supply and bunkering system shall be provided with safety accessories including but not limited to pressure relief devices, which shall comply with requirements of GB/T 29729.

5.2.4 Temperature-monitoring devices and pressure-monitoring devices shall be reasonably arranged for hydrogen storage, supply and bunkering system.

5.2.5 Except for piping directly communicating with outside atmosphere, purging-inerting nozzles shall be provided for remaining piping of hydrogen supply and

bunkering system. The positions of nozzles shall enable sufficient purging and inerting (by nitrogen or inert gas) of gas inside each piping segment.

5.2.6 Hydrogen-involved piping in hydrogen storage, supply and bunkering system shall comply with Guidelines for Ships Using Hydrogen Fuel.

5.3 Hydrogen Storage Device

5.3.1 Material Requirements

5.3.1.1 For materials used for manufacturing hydrogen cylinders, original certificate of quality issued by material manufacturer, or copy of certificate of quality affixed with official seal of material distributor and signed / stamped by handler shall be available.

5.3.1.2 Aluminium Liner

(1) The aluminium liner shall adopt 6061 aluminium alloy, and its chemical composition shall comply with Table 5.2:

Chemical-Composition Table Table 5.2

Element		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others		Al
												Individ.	Total	
Mass fraction, %	Min.	0.40	—	0.15	—	0.80	0.04	—	—	—	—	—		
	Max.	0.80	0.70	0.40	0.15	1.20	0.35	0.25	0.15	0.003	0.003	0.05	0.15	Remainder

(2) The aluminium-liner material shall be re-inspected and accepted by the hydrogen-cylinder manufacturer prior to use. The hydrogen-cylinder manufacturer shall conduct chemical-composition re-inspection by material heat-batch number.

(3) The aluminium-liner material shall comply with requirements of relevant standards. Ingots shall be subject to ultrasonic examination with ϕ 2 mm equivalent flat-bottom hole, and inspection methods shall comply with provisions of relevant standards.

5.3.1.3 Plastic Liner and Accessories

(1) Plastic liners shall be processed in accordance with qualified and approved forming processes, which shall be injection moulding, blow moulding, extrusion moulding or rotational moulding.

(2) Materials for plastic liners shall preferably be polyethylene (including modified polyethylene) or polyamide (including modified polyamide), and their hydrogen

compatibility shall satisfy requirements of Appendix C of GB/T 42612.

(3) The melting-peak temperature of plastic-liner material shall be no less than the value specified in design documents.

(4) Where raw-material for plastic liner is in pellet form, the melt-mass-flow rate of polyethylene (including modified polyethylene) and melt-volume-flow rate of polyamide (including modified polyamide) shall satisfy requirements of design documents.

(5) Where raw-material for plastic liner is in powder form, bulk density, powder flowability and particle-size distribution shall satisfy requirements of design documents.

(6) Accessories such as bottle-valve seat and O-ring shall comply with relevant requirements of GB/T 42612.

5.3.1.4 Resin

(1) Impregnating materials shall adopt thermosetting resin with high heat resistance and good stability such as epoxy resin or modified epoxy resin. The epoxy equivalent of resin shall be determined in accordance with relevant standards. The glass-transition temperature of resin materials shall be determined in accordance with relevant standards and shall be no less than 105 ℃.

(2) The performance and technical indexes of impregnating materials shall comply with provisions of corresponding national or industrial standards.

5.3.1.5 Carbon Fiber

(1) Load-bearing fibers shall be continuous untwisted carbon fiber; mixed fibers shall not be used.

(2) Mechanical properties such as tensile breaking strength, elongation at break and tensile modulus of each batch of carbon fiber shall comply with design requirements for hydrogen cylinders.

(3) The hydrogen-cylinder manufacturer shall conduct re-inspection on carbon-fiber materials batch-by-batch.

5.3.1.6 Glass Fiber

(1) Glass fiber shall only be used for outer-surface protective layer or galvanic-corrosion-prevention layer of hydrogen cylinders.

(2) S-type or E-type glass fiber shall be adopted, whose mechanical properties shall comply with hydrogen-cylinder design requirements.

(3) Re-inspection of mechanical properties of glass fiber shall be carried out batch-by-batch; fiber linear density and impregnated-fiber tensile strength shall be measured in accordance with GB/T 35544.

5.3.2 Design Requirements

5.3.2.1 Design of hydrogen cylinders shall comply with relevant requirements of GB/T 35544 and GB/T 42612.

5.3.2.2 Hydrogen cylinders shall be fitted with cylinder-neck combined valve consisting of manual stop valve, automatic stop valve, check valve, temperature-actuated pressure relief device, temperature sensor and other components, complying with GB/T 42536. Cylinder-neck combined valves shall be inspected.

5.3.2.3 The temperature-actuated pressure relief device shall adopt fusible-alloy plug or glass bulb with actuation temperature of (110 ± 5) ℃; fusible plugs and glass bulbs shall comply with GB/T 33215. The discharge port shall not face the cylinder body. Where a vent pipe is fitted at discharge port, the outlet shall be led upward and provided with rain and snow protection structure. Each hydrogen cylinder shall preferably be provided with an independent vent pipe. Where vent pipes are led out via a manifold pipe, vent-gas jet shall be prevented from impinging on non-actuated pressure relief devices in the hydrogen-cylinder bank, and the relief capacity of manifold pipe shall ensure safe relief of the whole hydrogen-cylinder bank.

5.3.2.4 The rated discharge capacity of temperature-actuated pressure relief device shall be no less than the safe-relief capacity of hydrogen cylinder. Rated discharge capacity and safe-relief capacity of hydrogen cylinder shall be calculated in accordance with GB/T 33215.

5.3.2.5 Hydrogen piping shall preferably adopt seamless metal piping; brittle materials such as cast iron, malleable cast iron, ductile cast iron and hydrogen-incompatible copper alloys shall not be used. Connections for hydrogen piping shall preferably adopt butt-welding or other hydrogen-leak-proof connection methods, complying with corresponding pressure-resistance and temperature-resistance requirements.

5.3.2.6 The design cycle number Nd for Class-A hydrogen cylinder is 11 000 cycles; the design cycle number Nd for Class-B hydrogen cylinder is 7 500 cycles.

5.3.2.7 Design of hydrogen cylinders shall satisfy relevant requirements of TSG 23. Class-A hydrogen cylinder shall have a service life of 15 years; Class-B hydrogen cylinder shall have a design service life of 10 years. Where the actual service life of hydrogen cylinder has not reached its design service life but filling cycles have reached design cycle number, the hydrogen cylinder shall be scrapped.

5.3.2.8 Allowable pressure of hydrogen cylinder shall be no less than maximum working pressure; allowable pressure equals 1.25 times nominal working pressure. Hydrostatic test pressure of hydrogen cylinder shall be no less than 1.5 times nominal working pressure. Fiber stress ratio shall be no less than 2.25. Minimum burst pressure of hydrogen cylinder shall be no less than 2.25 times nominal working pressure. Appropriate protective coating may be applied on outer surface of hydrogen cylinder. Where protective coating forms part of design, environmental tests shall be performed in accordance with recognized standards and pass acceptance. Service conditions of hydrogen cylinder exclude additional loads induced by external forces.

5.3.2.9 Stress analysis shall adopt finite-element method with appropriate hydrogen-cylinder analysis model established, to calculate stress and strain in aluminium liner and winding layer under autofrettage pressure, zero pressure after autofrettage, nominal working pressure, allowable pressure, hydrostatic test pressure and minimum burst pressure. Analysis model shall take material nonlinearity of aluminium liner, anisotropy of composite material and geometric nonlinearity of structure into consideration.

5.3.2.10 Hydrogen storage device shall be fitted with hydrogen-discharge pipe and purging nozzles.

5.4 Hydrogen Supply System

5.4.1 Pipes and valves in contact with hydrogen within hydrogen supply system shall have good hydrogen compatibility and operate stably for long-term service under hydrogen conditions.

5.4.2 Piping design of hydrogen supply system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.4.3 Inerting of hydrogen supply system shall comply with relevant requirements of

Guidelines for Ships Using Hydrogen Fuel and Guidelines for Hydrogen Bunkering Operations on Ships.

5.4.3 The hydrogen supply system shall be provided with manual emergency supply-shut-off function.

5.4.4 Hydrogen-gas detection-and-alarm devices shall be arranged at positions prone to hydrogen accumulation within hydrogen supply system. System design shall ensure that failure of a single hydrogen detector does not affect normal operation of hydrogen-gas detection-and-alarm devices.

5.4.5 The hydrogen supply system shall be properly earthed. Good contact without loosening shall be maintained among earthing device, earthing conductor, earthing wire and earthing point. Static-electricity earthing shall preferably share common earth electrode with other earthing circuits. Where dedicated static-electricity earthing is adopted, earthing resistance shall be no more than 10 Ω. Flange joints on hydrogen piping shall be bonded with metal jumpers; bonding resistance shall be less than 0.03 Ω.

5.5 Bunkering System

5.5.1 Pipes and valves in contact with hydrogen within bunkering system shall have good hydrogen compatibility and operate stably for long-term service under hydrogen conditions.

5.5.2 Piping design of bunkering system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

5.5.3 Inerting of bunkering system shall comply with relevant requirements of Guidelines for Ships Using Hydrogen Fuel and Guidelines for Hydrogen Bunkering Operations on Ships.

5.5.4 On-board bunkering system shall support real-time communication with shore-side bunkering system. In case of communication interruption, hydrogen bunkering shall be stopped or switched to non-communication mode bunkering under safe conditions.

5.5.5 The bunkering system shall be provided with manual emergency bunkering-shut-off function.

5.5.6 Hydrogen-gas detection-and-alarm devices shall be arranged at positions prone to

hydrogen accumulation within bunkering system. System design shall ensure that failure of a single hydrogen detector does not affect normal operation of hydrogen-gas detection-and-alarm devices.

5.5.7 The bunkering system shall be properly earthed. Good contact without loosening shall be maintained among earthing device, earthing conductor, earthing wire and earthing point. Static-electricity earthing shall preferably share common earth electrode with other earthing circuits. Where dedicated static-electricity earthing is adopted, earthing resistance shall be no more than 10 Ω. Flange joints on hydrogen piping shall be bonded with metal jumpers; bonding resistance shall be less than 0.03 Ω.

5.6 Control, Monitoring and Safety System

The control, monitoring and safety system of hydrogen storage, supply and bunkering system shall provide alarm and safety functions specified in Table 12.4.1 of Guidelines for Ships Using Hydrogen Fuel. Remote display of alarm information as well as acoustic-visual alarm shall be available.

In case of system failures specified in Table 12.4.1 of Guidelines for Ships Using Hydrogen Fuel and other failures developing too rapidly for manual intervention, the safety system shall automatically shut off the fuel supply system.

5.6.1 Installation Requirements

5.6.1.1 Suitable instrument devices shall be provided for local and remote indication of important parameters of hydrogen storage, supply and bunkering system, so as to ensure safety management of all fuel equipment and bunkering operations.

5.6.1.2 A locally-readable pressure indicator shall be fitted to indicate pressure between ship-board system stop valve and hose ship-shore coupling.

5.6.1.3 At least one locally-readable pressure gauge shall be fitted on each hydrogen main manifold.

5.6.1.4 Each hydrogen cylinder shall be fitted with a local pressure gauge clearly marked with maximum permissible pressure and minimum permissible pressure for hydrogen cylinder. Pressure indication shall also be provided at remote positions (e.g. wheelhouse, machinery-space control room or ship safety centre, etc.). In addition, high-pressure and low-pressure alarms shall be provided at manned spaces, and acoustic-visual alarm shall be triggered when preset maximum / minimum pressure

values are reached.

5.6.1.5 Hydrogen cylinder shall be fitted with pressure sensor. Acoustic-visual alarm shall be triggered when internal pressure of cylinder reaches preset alarm value (high pressure or low pressure). Fuel output shall be cut off in a timely manner when pressure drops below minimum pressure required for safe operation of hydrogen-consuming equipment.

5.6.2 Function and Safety Requirements

5.6.2.1 Abnormal pressure / temperature associated with equipment of hydrogen storage, supply and bunkering system shall be monitored, and acoustic-visual alarm shall be triggered when limit values are exceeded.

5.6.2.2 Gas-leakage conditions of hydrogen storage, supply and bunkering system shall be monitored, and acoustic-visual alarm shall be triggered when limit values are exceeded.

5.6.2.3 For electrical equipment involved in hydrogen storage, supply and bunkering system which shall adopt qualified explosion-proof equipment according to hazardous-area classification requirements, its explosion-proof category shall be no lower than IIC or IIB+H2, and temperature class shall be no lower than T1.

6 Raw Materials and Components

Raw materials and components of products shall be controlled in accordance with relevant requirements of Guidelines for Ships Using Hydrogen Fuel.

7 Type Test

Type test shall be carried out for hydrogen cylinders in accordance with requirements of this Clause. For hydrogen storage device, hydrogen supply and bunkering system, piece / batch survey shall be performed in conjunction with shipboard projects in accordance with approved drawings.

7.1 Type-test Requirements for Hydrogen Cylinders:

7.1.1 The quantity of hydrogen cylinders of the same batch for type test shall be no less than 30 units, with 5 liners as base sample size.

(1) One liner shall be randomly selected for tensile test, metallographic test,

cold-bending or flattening test.

(2) Quantities of hydrogen cylinders randomly selected for type-test items are as follows:

① For Class-A hydrogen cylinder: 3 units for hydrostatic burst test; 2 units for ambient-temperature pressure-cycling test; 1 unit for fire test; 1 unit for extreme-temperature pressure-cycling test; 1 unit for accelerated stress-rupture test; 1 unit for flaw-tolerance test; 1 unit for environmental test; 1 unit for drop test; 1 unit for hydrogen-cycling test; 1 unit for bullet-impact test.

② For Class-B hydrogen cylinder: 3 units for hydrostatic burst test; 3 units for ambient-temperature pressure-cycling test; 1 unit for fire test; 1 unit for durability test; 1 unit for service-performance test.

7.1.2 All liners and hydrogen cylinders subjected to type test shall be rendered unusable after test completion.

7.1.3 Type-test items and requirements.

Type-Test Items and Requirements Table 7.1.3

Test Item		**Test Quantity**	**Test Requirements**
Raw Materials	Aluminium Liner	Per heat/lot	1. Raw-material certificate of quality shall be available;2. The liner shall adopt 6061 aluminium alloy, with chemical composition complying with GB/T 35544;3. Aluminium-liner material shall comply with

			relevant standards: plate per GB/T 3880.1, GB/T 3880.2 and GB/T 3880.3; tube per GB/T 4437.1; extruded bar per GB/T 3191; ingot per YS/T 67. Ingots shall be ultrasonically inspected with φ2 mm equivalent flat-bottom hole, inspection method complying with YS/T 1188.
	Plastic Liner	Per batch	1. Raw-material certificate of quality shall be available;2. Plastic liner shall be processed by an approved forming process: injection moulding, blow moulding, extrusion moulding or rotational moulding.
	Resin	Per batch	1. Impregnating material shall be a thermosetting resin with high heat resistance and

			good stability, such as epoxy resin or modified epoxy resin;2. Epoxy equivalent shall be determined in accordance with GB/T 4612;3. Glass-transition temperature shall be determined in accordance with GB/T 19466.2, and shall be no less than 105 ℃.
	Carbon Fiber	Per batch	1. Load-bearing fiber shall be continuous untwisted carbon fiber; mixed fibers are prohibited;2. Mechanical properties of each batch of carbon fiber shall comply with the hydrogen-cylinder design document;3. Linear density (nominal count) shall be determined per GB/T 3362 or GB/T 30019;4. Tensile strength of resin-impregnated

				fiber shall be determined per GB/T 3362 or GB/T 26749.
	Glass Fiber	Per batch		1. S-type or E-type glass fiber shall be adopted, with mechanical properties complying with the hydrogen-cylinder design document;2. Performance re-test shall be carried out in accordance with GB/T 7690.3.
Aluminium Liner	Wall Thickness	Each cylinder		Comply with Clause 5.6.1 of GB/T 35544 and approved drawings.
	Manufacturing Tolerance	Each cylinder		Comply with Clause 5.6.1 of GB/T 35544.
	Inner-outer Surface	Each cylinder		Comply with Clause 5.6.2 of GB/T 35544.
	Tensile Test	1 cylinder randomly selected		3 specimens/cylinder
	Metallographic Test	Each cylinder	1 specimen/cylinder	Comply with Clause 5.6.4.3 of GB/T 35544.

	Cold-bending or Flattening Test		2 bend-specimens/cylinder; 1 flatten-specimen/cylinder	Comply with Clause 5.6.4.3 of GB/T 35544.
	Hardness Test		Comply with Clause 5.6.5 of GB/T 35544 and approved drawings.	1. Either test item shall be selected; 2. Comply with Clause 5.6.4.4 or 5.6.4.5 of GB/T 35544.
	Mass, Wall-thickness and Manufacturing Deviation	Each cylinder		Comply with Clause 5.6.1 of GB/T 42612.
Plastic Liner	Inner-outer Surface	Each cylinder		Comply with Clause 5.6.2 of GB/T 42612.
	Base-material Tensile Test	1 cylinder		Comply with Clause 5.6.3 of GB/T 42612.
	Weld-joint Inspection (tensile test, dissection inspection)	1 cylinder		Comply with Clause 5.6.4 of GB/T 42612.
	Vicat Softening Temperature	1 cylinder		Comply with Clause 5.6.5 of GB/T 42612.
	Valve-seat Thread	Each cylinder		Comply with Clause 5.6.6.1 of GB/T 42612.
	Dissection Inspection of Valve-seat-to-plastic-liner Joint	1 cylinder		Comply with Clause 5.6.6.2 of GB/T 42612.
	Class-A and Class-B	Winding-layer Inter-laminar Shear Test		6 per batch

Hydrogen Cylinder	Class-A	Winding Layer Tensile Test	6 per batch	Comply with Clause 5.7.1.1 of GB/T 35544.
		Winding Layer Visual Inspection	Each cylinder	Comply with Clause 5.7.1.1 of GB/T 35544 and approved drawings.
		Hydrostatic Test	Each cylinder	1. Visual inspection; 2. Defects such as fiber exposure, fiber breakage, resin lump, delamination and unimpregnated fiber are not allowed.
		Tightness Test	Each cylinder	Comply with Clause 5.7.3 of GB/T 35544.
		Hydrostatic Burst Test	3 cylinders	Comply with Clause 5.7.4 of GB/T 35544.
		Fire Test	1 cylinder	Comply with Clause 5.7.5 of GB/T 35544.
		Torque Test (Plastic Liner Hydrogen Cylinder)	1 cylinder	Comply with Clause 5.7.7 of GB/T 35544.

		Ambient Temperature Pressure Cycling Test	2 cylinders	Comply with Clause 5.7.8 of GB/T 42612.
	Class-B	Extreme Temperature Pressure Cycling Test	1 cylinder	Comply with Clause 5.7.6 of GB/T 35544.
		Accelerated Stress Rupture Test	1 cylinder	Comply with Clause 5.7.8 of GB/T 35544.
		Flaw Tolerance Test	1 cylinder	Comply with Clause 5.7.9 of GB/T 35544.
		Environmental Test	1 cylinder	Comply with Clause 5.7.10 of GB/T 35544.
		Drop Test	1 cylinder	Comply with Clause 5.7.11 of GB/T 35544.
		Hydrogen Cycling Test	1 cylinder	Comply with Clause 5.7.12 of GB/T 35544.
		Bullet Impact Test	1 cylinder	Comply with Clause 5.7.13 of GB/T 35544.
		Ambient Temperature Permeation Test	1 cylinder	Comply with Clause 5.7.14 of GB/T 35544.

		Ambient Temperature Pressure Cycling Test	3 cylinders	Comply with Clause 5.7.16 of GB/T 42612.
		Durability Test	1 cylinder	Comply with Clause 5.7.6 of GB/T 35544.
		Service Performance Test	1 cylinder	Comply with Clause 5.7.15 of GB/T 35544.
				Comply with Clause 5.7.16 of GB/T 35544.

7.1.4 Design Modification

7.1.4.1 Design modification may permit reduction of type-test items; re-type-test shall be performed for items specified in Table 7.1.4 according to modification scope.

Items Subject to Re-Type-Test upon Design Modification Table 7.1.4

Design Modification	Test Items														
	Class- A & B							Class- A							Class- B
	Liner Type Test Items	**Hydrostatic Test**	**Inter-laminar Shear Test**	**Winding-layer Tensile Test**	**Hydrostatic Burst Test**	**Ambient-temperature Pressure-cycling Test**	**Fire Test**	**Extreme-temperature Pressure-cycling Test**	**Accelerated Stress-rupture Test**	**Flaw-tolerance Test**	**Environmental Test**	**Drop Test**	**Hydrogen-cycling Test**	**Projectile Test**	**Durability Test**	**Service-performance Test**
Fiber Manufacturer		√	√	√	√	√	√		√			√		√	√	

Equivalent Fiber Material [a]		√	√	√	√	√			√			√				
New Resin Material		√	√	√	√[b]	√[b]	√	√	√	√	√	√		√	√	
Equivalent Resin Material [a]		√	√	√	√[b]	√[b]			√							
Liner OD change ≤20% [c]		√			√[b]	√[b]						√		√[d]	√	
Liner OD change >20% [c]		√			√	√	√					√	√[e]	√	√	√[e]
Length change ≤50%		√			√[b]	√[b]	√[e]									
Length change >50%		√			√[b]	√[b]	√					√	√[e]		√	√[e]
Liner wall-thickn	√	√			√	√						√			√	

ess reduction																
End structure					√	√										
Neck thread	√[g]	√			√[b]	√[b]										
Glass-fiber protective layer											√				√	
Cylinder valve / TPRD end plug							√[i]						√[j]			√[j]

a Applies only to changes in material properties or the material manufacturer; the design change item for equivalent fiber materials applies only to material produced by the same material manufacturer.

b Only one cylinder is required for testing.

c Applies only when the diameter changes and the winding layer wall thickness maintains the same or a lower stress level as the original design (e.g., if the diameter increases, the wall thickness shall increase proportionally).

d Testing shall be performed only when the cylinder diameter is reduced.

e Testing shall be performed only when the cylinder volume is increased.

f A change of ≤10% in the nominal diameter of the neck thread shall not be regarded as a change in thread dimensions, provided that the same or a lower stress level as the original design is maintained.

g Only the neck thread in the liner type test is required to be tested.

h Refers to a change in the material or thickness of the protective layer that forms part of the design.

i Applies only to a change in the manufacturer of the cylinder valve or TPRD end plug; a change in the TPRD type on the cylinder valve or TPRD end plug; a reduction in the TPRD discharge bore; a mass change of the cylinder valve or TPRD end plug exceeding 30%; or structural changes that may affect the test results.

j Applies only when: (1) the manufacturer of the cylinder valve or TPRD end plug is changed; (2) the sealing dimensions and tolerances of the modified cylinder valve or TPRD end plug exceed the range of the original cylinder valve; or (3) the sealing structure of the cylinder valve or TPRD end plug is changed.

7.2 Handling of Non-conformities

If non-conforming items are found in type test and batch test, handling shall be carried out in accordance with the following provisions:

7.2.1 Aluminium Liner

(1) If non-conformity is caused by test operation anomaly or measurement error, the test may be repeated.

(2) Where test operation and measurement are correct, the root-cause of non-conformity shall be identified first, and then handled in accordance with the following rules:

① If non-conformity of aluminium liner is confirmed to be caused by improper heat treatment, re-heat treatment of this batch of aluminium liners is permitted, but the number of heat-treatment cycles shall not exceed 2. The re-heat-treated batch of aluminium liners shall be regarded as a new batch and subject to batch test again;

② If non-conformity of aluminium liner is caused by other reasons, the whole batch of aluminium liners shall be scrapped.

7.2.2 Hydrogen Cylinders

Where non-conforming items occur in type test or batch test, and evidence proves that non-conformity results from test operation anomaly or measurement error, re-inspection is permitted.

In case of non-conformity in batch test, two additional hydrogen cylinders shall be randomly selected for the relevant test item. If both additional cylinders pass the test, this batch is acceptable; if any one of them fails, this batch shall be rejected.

8 Piece / Batch Survey

8.1 Hydrogen Cylinders

8.1.1 Piece / batch survey for issuing marine-use hydrogen cylinder product certificates shall be performed after the manufacturer has obtained factory approval, unless special consideration is given. Piece / batch survey shall be carried out for marine-use hydrogen

cylinders. For marine-use hydrogen cylinders without approval, piece / batch survey shall be conducted in accordance with type-test requirements.

8.1.2 Piece / batch survey for CCS-approved marine-use hydrogen cylinders shall be implemented according to the approved product inspection plan upon approval. The test items specified below shall be included:

Piece-and-Batch Factory Inspection Items Table 8.1.2

Inspection Item		**Inspection Quantity**		**Inspection Mode**
Raw material	Inspection Item	Inspection Quantity		Inspection Mode
	Aluminium Liner	Per heat batch		Report review
	Resin	Per batch		Report review
	Carbon Fiber	Per batch		Report review
Aluminium liner	Glass Fiber	Per batch		Report review
	Wall Thickness	Sampling		Sampling inspection plus report review
	Manufacturing Tolerance	Sampling		Sampling inspection plus report review
	Inner-outer Surface	Sampling		Sampling inspection plus report review
	Cylinder-neck Thread	1 unit selected at random	3 specimens/unit	Sampling inspection plus report review
	Tensile Test		1 specimen/unit	Witnessed test
	Metallographic Test		2 bend-specimens/unit; 1	Witnessed test

			flatten-specimen/unit	
	Cold-bending Test or Flattening Test		Inspection Quantity	Witnessed test
Plastic liner	Hardness Test		Unit-by-unit	Report review
	Mass, Wall-thickness and Manufacturing Deviation		Sampling	Sampling inspection plus report review
	Inner-outer Surface		Sampling	Sampling inspection plus report review
	Base-material Tensile Test			Sampling inspection plus report review
	Weld-joint Inspection (tensile test, dissection inspection)		Sampling	Sampling inspection plus report review
	Valve-seat Thread		Sampling	
	Dissection Inspection of Valve-seat-to-plastic-liner Joint (dimension check, low-pressure tightness check)		Sampling	Sampling inspection plus report review
Hydrogen cylinder	Class- A & B	Winding-layer Visual Inspection	Sampling	Sampling inspection plus report review
		Hydrostatic Test	Sampling	Sampling inspection plus report review

		Tightness Test	Sampling	Sampling inspection plus report review
			Sampling	Sampling inspection plus report review
		Hydrostatic Burst Test	Sampling	Sampling inspection plus report review

8.1.3 Handling of non-conformities shall be in accordance with Clause 7.2.

8.2 Hydrogen Storage Device

8.2.1 Visual and Structural Inspection

During visual and structural inspection of the hydrogen storage device, system appearance, marking, interfaces and structure shall be checked, and the following requirements shall be satisfied:

(1) The outer surface shall be clean and free of mechanical damage; contact points of interfaces shall be free of rust;

(2) The product nameplate shall be clearly legible.

8.2.2 Tightness Test

Nitrogen-helium mixed gas shall be adopted for tightness test. The volume fraction of helium in nitrogen-helium mixed gas shall be no less than 10 %, and the specific content shall be determined by test to ensure test accuracy. The leakage rate of nitrogen-helium mixed gas shall be converted into equivalent hydrogen leakage rate. The hydrogen storage system shall be filled with nitrogen-helium mixed gas up to the maximum temperature-rise pressure. The hydrogen storage system shall be placed in an enclosed space, and the enclosed space shall be connected to gas-detection instruments (such as helium mass spectrometer, quadrupole mass spectrometer, gas chromatograph, etc.). The vacuum chamber shall be evacuated to achieve vacuum degree lower than 2 Pa. The hydrogen storage system shall stand for more than 30 min at room temperature, and vacuum-degree and leakage-rate data shall be read from gas-detection instruments.

Note: Before placing the hydrogen storage system into the enclosed space for tightness test, special leak-detecting liquid shall be used to check for obvious leakage points at all potential leakage positions.

8.2.3 Over-pressure Safety Performance Test The hydrogen pressure of the hydrogen storage device shall be raised above the actuation pressure of the pressure relief device provided by the manufacturer, and normal operation of the pressure relief device shall be verified. The set pressure of pressure relief valve shall be lower than 0.8 times the maximum allowable pressure of hydrogen cylinders, valves, joints and hydrogen piping, and shall be no greater than 1.5 times the rated hydrogen-charging pressure of the system. 8.3 Hydrogen Supply and Bunkering System 8.3.1 Visual and Structural Inspection Visual inspection together with routine review of design drawings and instructions shall be performed to verify conformity between the physical product and the approved drawings and technical documents. 8.3.2 Piping Strength Test Nitrogen shall be used as test medium for strength test of piping of the hydrogen supply and bunkering system. The outlet of the hydrogen supply system shall be connected to the gas source, the safety valve shall be replaced with blanking plug, pressure shall be gradually raised up to 1.5 times design pressure and held for 30 min. Acceptance criteria: no leakage, no visible deformation and no abnormal noise during pressure holding. The inlet of the bunkering system shall be connected to the gas source, the safety valve shall be replaced with blanking plug, pressure shall be gradually raised up to 1.5 times design pressure and held for 30 min. Acceptance criteria: no leakage, no visible deformation and no abnormal noise during pressure holding.

8.3.3 Tightness Test

Nitrogen shall be used as test medium for tightness test of hydrogen supply and bunkering system.

Connect outlet of hydrogen supply system to gas source, replace safety valve with blanking plug, raise pressure step-by-step and hold for 15 min at each pressure step. Apply special leak-detecting liquid to full piping system. After confirming no visible bubbles, raise pressure step-by-step up to maximum working pressure and hold for 12 h. After temperature correction, pressure drop during test shall not exceed 1 % of test pressure and shall not exceed 0.05 MPa.

Connect inlet of bunkering system to gas source, replace safety valve with blanking plug, raise pressure step-by-step and hold for 15 min at each pressure step. Apply special leak-detecting liquid to full piping system. After confirming no visible bubbles,

raise pressure step-by-step up to maximum working pressure and hold for 12 h. After temperature correction, pressure drop during test shall not exceed 1 % of test pressure and shall not exceed 0.05 MPa.

8.3.4 Function Test Verify that the hydrogen supply system fulfils the functions specified in Clause 5.4, the bunkering system fulfils the functions specified in Clause 5.5, and the control, monitoring and safety system fulfils the functions specified in Clause 5.6.