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Liquid hydrogen — Land vehicle fuel tanks

Hydrogène liquide — Réservoirs de carburant pour véhicules terrestres

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 13985 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

Introduction

The fuel tanks described in this International Standard are intended to be used in conjunction with the fuelling system interface described in ISO 13984.

Liquid hydrogen — Land vehicle fuel tanks

1 Scope

This International Standard specifies the construction requirements for refillable fuel tanks for liquid hydrogen used in land vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided.

This International Standard is applicable to fuel tanks intended to be permanently attached to land vehicles.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 188:1998, *Rubber, vulcanized or thermoplastic — Accelerated ageing and heat resistance tests*

ISO 1431-1, *Rubber, vulcanized or thermoplastic — Resistance to ozone cracking — Part 1: Static and dynamic strain testing*

ISO 2768-1, *General tolerances — Part 1: Tolerances for linear and angular dimensions without individual tolerance indications*

ISO 6957, *Copper alloys — Ammonia test for stress corrosion resistance*

ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests*

ISO 13984, *Liquid hydrogen — Land vehicle fuelling system interface*

ISO 21010, *Cryogenic vessels — Gas/materials compatibility*

ISO 21013-3, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination*

ISO 21014, *Cryogenic vessels – Cryogenic insulation performance*

ISO 21028-1, *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below –80 °C*

ISO 21029-1:2004, *Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 1: Design, fabrication, inspection and tests*

ISO 23208, *Cryogenic vessels — Cleanliness for cryogenic service*

3 Terms and definitions

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

3.1
accessory
device fixed directly to the inner tank or outer jacket of a fuel tank such as a pressure relief valve, shut-off valve, non-return valve or level gauge

3.2
boil-off management system
system that controls the boil off of gas under normal conditions

3.3
burst pressure
pressure that causes the rupture of a pressure vessel subjected to a constant increase of pressure during a destructive test

3.4
design temperature
temperature of the inner tank, the outer jacket and all other accessories to which fabrication drawings, inspections and physical measurements such as volume are referred

3.5
fuel tank
vessel used for the storage of cryogenic hydrogen

3.6
hydrogen conversion system
system designed for the consumption of hydrogen for energy transformation

3.7
impermissible fault range
pressure range within which an unwanted event is to be expected (see Annex A)

3.8
inner tank
part of the fuel tank that contains liquid hydrogen

3.9
level gauge
device that measures the level of liquid hydrogen in the fuel tank

3.10
maximum allowable working pressure
MAWP
maximum pressure to which a component is designed to be subjected to and which is the basis for determining the strength of the component under consideration

3.11
normal operating range
range planned for the process values (see Annex A)

NOTE In the case of inner tanks, the normal operating range of the inner tank pressure is from 0 MPa to the set pressure of the primary pressure relief valve, which is lower than or equal to the MAWP of the inner tank.

3.12
outer jacket
part of the fuel tank that encases the inner tank(s) and its insulation system

3.13
outer pressure
pressure acting on the outside of the inner tank or outer jacket

3.14
permissible fault range
range between the normal operating range and the impermissible fault range (see Annex A)

3.15
pressure
gauge pressure against atmospheric pressure, unless otherwise stated

3.16
thermal autonomy
time of the pressure increase in the inner tank measured from a starting pressure of 0 MPa at the corresponding boiling point of hydrogen (–253 °C) up to MAWP of the inner tank

NOTE The thermal autonomy is a measure of the quality of the insulation of the fuel tank.

4 Requirements

4.1 General requirements

The fuel tank and its accessories shall function in a correct and safe way. It shall withstand and remain gas tight when subjected to the mechanical, thermal and chemical stresses specified in this International Standard.

4.2 Mechanical stresses

4.2.1 Inner/outer pressure

4.2.1.1 Inner tank

The inner tank shall be designed to resist the following inner test pressure:

$$p_{test} = 1{,}3\ (\text{MAWP} + 0{,}2)$$

where

p_{test} is the test pressure, expressed in megapascals (MPa);

MAWP is the maximum allowable working pressure of the inner tank, expressed in megapascals (MPa).

The inner tank and its accessories shall be designed to resist an outer pressure of 0,2 MPa.

4.2.1.2 Outer jacket

The outer jacket shall be designed to resist an outer pressure of 0,2 MPa.

4.2.2 Accelerations

4.2.2.1 General

The fuel tank and its accessories shall be mounted and protected so that the accelerations shown in Table 1 can be absorbed without structural damage to the fuel tank and its accessories. No uncontrolled release of hydrogen is permitted.

Table 1 — Accelerations

Vehicle categories	Accelerations
Vehicles of categories M_1 and N_1	20 g in the direction of travel 8 g horizontally perpendicular to the direction of travel
Vehicles of categories M_2 and N_2	10 g in the direction of travel 5 g horizontally perpendicular to the direction of travel
Vehicles of categories M_3 and N_3	6,6 g in the direction of travel 10 g horizontally perpendicular to the direction of travel
The vehicle categories include the following: — Category M_1: Vehicles used for the transportation of passengers and comprising not more than eight seats in addition to the driver's seat. — Category M_2: Vehicles used for the transportation of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass that does not exceed 5 000 kg. — Category M_3: Vehicles used for the transportation of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 000 kg. — Category N_1: Vehicles used for the transportation of goods and having a maximum mass that does not exceed 3 500 kg. — Category N_2: Vehicles used for the transportation of goods and having a maximum mass exceeding 3 500 kg, but not exceeding 12 000 kg. — Category N_3: Vehicles used for the transportation of goods and having a maximum mass exceeding 12 000 kg.	

4.2.2.2 Inner and outer support

When exposed to the accelerations described in Table 1, the stress in the support elements shall not exceed 50 % of the minimum ultimate tensile strength of the material (R_m, calculated according with the linear stress model).

The allowable stress in the support elements may not have to be calculated if it can be demonstrated that the fuel tank supports the accelerations given in Table 1 without any structural damage to the inner tank or its supports.

4.3 Thermal stresses

4.3.1 Design temperature

The design temperature of the inner tank, the outer jacket and the accessories shall be 20 °C. In addition, the inner tank, the outer jacket and the accessories shall be designed to withstand a temperature range from the lowest to the highest possible operating temperatures that will be encountered in service.

4.3.2 Ambient temperature

The fuel tank shall be designed to withstand ambient temperatures ranging from –40 °C to 85 °C. If the fuel tank is to be installed in areas of internal heat sources such as the internal combustion engine compartment of a vehicle, the fuel tank shall be designed for an ambient temperature of 120 °C, or a lower value if substantiated by calculations.

4.3.3 Operating temperature

The thermal stresses produced by the operating conditions shall be considered. The inner vessel and the other components that may be in contact with liquid hydrogen shall be designed to operate at –253 °C.

4.4 Materials

The materials of the fuel tank and its accessories shall be compatible, as applicable, with:

a) hydrogen;

b) other media and fluids found in a land vehicle environment, such as coolants and battery acid.

NOTE Recommendations for lowering the susceptibility to hydrogen embrittlement are given in Annex B.

Materials used at low temperatures shall meet the toughness requirements of ISO 21028-1. For non-metallic materials, low temperature suitability shall be validated by an experimental method, taking into account the service conditions.

The materials used for the outer jacket shall ensure the integrity of the insulation system, and their elongation at fracture, at the temperature of liquid nitrogen, shall be at least 12 %.

A corrosion allowance does not need to be added for the inner tank. A corrosion allowance does not need to be added on other surfaces, if they are protected against corrosion.

For welded vessels, welds shall have properties equivalent to those specified for the parent material for all temperatures that the material may encounter.

4.5 Design

4.5.1 Design validation

The design of the fuel tank shall be validated in accordance with the design options specified in 10.1 of ISO 21029-1:2004.

4.5.2 Inner tank and outer jacket

Unless the design is validated as per option 10.1.3 of ISO 21029-1:2004, the design of the inner tank and the outer jacket shall meet all the design rules specified in 10.3 of ISO 21029-1:2004. If the design is validated as per option 10.1.3 of ISO 21029-1:2004, the exceptions specified in 10.1.3 of ISO 21029-1:2004 shall apply.

Unless indicated otherwise, the general tolerances of ISO 2768-1 shall apply.

4.6 Insulation

4.6.1 General requirements

The insulation system installed on a fuel tank shall meet the requirements of ISO 21014.

Except in the vicinity of the pressure relief valves, no ice shall form on the outer wall of the fuel tank under normal operating conditions.

When exposed to fire as per 5.3, the thermal autonomy of the fuel tank, equipped with vacuum insulation and fire protection measures (if present), shall be at least 5 min.

The insulation of the accessories shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is to be provided for collecting and vaporizing the liquefied air. If such a system is to be used, the materials of accessories shall be compatible with an atmosphere enriched with oxygen according to ISO 21010.

4.6.2 Getters/absorbents

Getters/absorbents reacting with hydrogen outgas and/or moisture and atmospheric gas contaminants may be used for vacuum maintenance and assisting the insulation performance.

4.7 Accessories

4.7.1 General requirements

Accessories shall have a minimum working pressure equal to the MAWP of the inner tank.

No casting shall be used for any of the accessories.

4.7.2 Pressure relief valves for the inner tank

The inner tank shall be protected with a primary pressure relief valve that limits the pressure inside the inner tank to not more than 121 % of the MAWP of the inner tank. This pressure relief valve shall be connected directly to the highest part of the inner tank in its design position under normal operating conditions.

The inner tank shall also be protected by a secondary pressure relief valve that shall not operate below 110 % of the set pressure of the primary pressure relief valve. The secondary pressure relief valve shall ensure that the pressure in the inner tank does not, under any circumstances, exceed the permissible fault range of the inner tank. For example, in the case of steel inner tanks, the maximum set pressure of the secondary pressure relief valve shall be 136 % of the MAWP of the inner tank. For other materials, an equivalent level of safety shall be applied based on the permissible fault range.

The inner tank pressure relief valves shall, after discharge, close at a pressure higher than 90 % of the set pressure of the pressure relief valve and remain closed at all lower pressures.

The sizing of the inner tank pressure relief valves shall be done in accordance with ISO 21013-3.

The rating of the inner tank pressure relief valves shall be clearly marked. A lead seal or equivalent system shall be installed on these pressure relief valves in order to provide a physical impediment to tampering.

4.7.3 Lines incorporating pressure relief valves

No isolating valve shall be installed between the inner tank and its pressure relief valves. The primary and the secondary pressure relief valves of the inner tank may be connected to the inner tank by the same line.

The lines in front of and behind the pressure relief valves shall not impede their function.

4.7.4 Protection of the outer jacket

The outer jacket shall be protected by means of a pressure relief device preventing bursting of the outer jacket or collapsing of the inner tank.

4.7.5 Automatic shut-off valves and non-return valves

The fuel tank shall be provided with shut-off valves for the purpose of securing the refuelling lines and the fuel supply lines to the hydrogen conversion system(s).

All hydrogen fuel supply lines to the hydrogen conversion system(s), except the lines to the boil-off management system, shall be secured with automatic shut-off valves. These valves shall be mounted directly on or within the fuel tank.

The refuelling line shall be secured by either a manually or an automatically operated shut-off valve, which shall always be closed except during the refuelling process. If the fuelling connector receptacle is not mounted directly on the fuel tank, a second isolation valve shall be used. This valve may be a manual shut-off valve, an automatic shut-off valve or a non-return valve. When two isolation valves are required, one shall be mounted directly on or within the fuel tank.

The automatic shut-off valves shall close with loss of motive power.

4.7.6 Overfill protection gauge

The fuel tank shall be equipped with a measuring gauge that measures the level of liquid in the inner tank as it approaches the maximum filling level with an accuracy of ± 2 % of the inner tank capacity.

4.7.7 Maximum filling level

A system shall be provided for preventing the fuel tank from being overfilled. This system may work in conjunction with the refuelling station.

The filling process shall not cause any pressure relief valve to operate during the filling process. The filling process shall not lead to operating conditions that the boil-off management system is not designed for, and therefore cannot handle.

Under all circumstances and regardless of the fuel condition and the maximum operating pressure of the inner tank, the filling volume of liquid hydrogen shall not exceed the maximum filling level of the inner tank specified by the fuel tank manufacturer.

4.7.8 Pressure maintaining system

The fuel tank shall be equipped with a pressure maintaining system that is capable of maintaining the fuel tank at its required operating pressure at the maximum product consumption and duration, as specified by the manufacturer. Liquid air that may form during the pressure maintaining system operation shall be collected and discharged to a safe location.

4.7.9 Inspection openings

Inspection openings shall not be provided on the inner tank or the outer jacket.

4.8 Manufacturing and assembly

The manufacturing of the fuel tank (e.g. forming, heat treatment, welding) shall be carried out according to Clause 11 of ISO 21029-1:2004.

The number of joints on the fuel tank should be minimized. For metallic materials, joints within the annular space between the inner tank and outer jacket shall be welded.

The accessories of the fuel tank shall be mounted in a way that the system and its components function properly and are gas tight.

5 Type tests

5.1 Approval of new designs

Type tests shall be conducted on each new design, and on finished fuel tanks that are representative of normal production, complete with identification marks. All fuel tanks subjected to burst pressure and thermal autonomy tests shall be made unserviceable after the tests are completed.

The fuel tank manufacturer shall retain the type test results for the intended life of the fuel tank design. The test data shall also document the dimensions, wall thickness and weight of each of the test fuel tanks. If more fuel tanks are subjected to the tests than are required, all results shall be documented.

5.2 Inner tank burst pressure test

One sample of a finished inner tank shall be subjected to a burst pressure test in accordance with C.1 and meet the requirements therein.

5.3 Thermal autonomy test

Two finished fuel tanks shall be subjected to a thermal autonomy test in accordance with C.2 and meet the requirements therein.

5.4 Maximum filling level test

Two finished fuel tanks shall be subjected to a maximum filling level test in accordance with C.3 and meet the requirements therein.

5.5 Accessory type tests

Each fuel tank accessory, with the exception of pressure relief valves (see 4.7.2) and cryogenic valves (see 4.7.5), shall be subjected to type tests according to Annex D.

6 Routine tests and inspection

6.1 General

The tests and inspections specified in 6.2 to 6.6 shall be performed on each fuel tank.

6.2 Pressure test

The inner tank and the pipework situated between the inner tank and the outer jacket shall be subjected to an inner hydrostatic pressure test at room temperature with a suitable test media.

The test pressure shall be:

$$p_{\text{test}} = 1{,}3\ (\text{MAWP} + 0{,}2)$$

where

p_{test} is the test pressure, expressed in megapascals (MPa);

MAWP is the maximum allowable working pressure of the inner tank, expressed in megapascals (MPa).

The pressure test shall be performed before the outer jacket is mounted. The pressure in the inner tank shall be increased at an even rate until the test pressure is reached. The inner tank shall remain under the test pressure without the addition of test media for at least 10 min to establish that the pressure is not decreasing.

After the test, the inner tank shall not show any signs of visible permanent deformation nor leaks. Inner tanks that do not pass the test because of permanent deformation shall be rejected and shall not be repaired. Inner tanks that do not pass the test because of leakage may be accepted after repair and retesting.

Upon completion of the test, the inner tank shall be emptied, cleaned, and dried according to ISO 23208.

A test report shall be drawn up and the inner tank shall be marked if accepted.

6.3 Leak test

After final assembly, the fuel tank shall be helium leak tested with a gas mixture containing a minimum of 10 % of helium using a mass spectrometer leak detector capable of detecting leaks ranging from 1×10^{-9} cm^3/s at 20 °C and 101,325 kPa to 10×10^{-9} cm^3/s at 20 °C and 101,325 kPa. There shall be no detectable leak. The fuel tank accessories shall be leak tested in accordance with D.2, except that the test shall be performed only at 20 °C ± 5 °C.

6.4 Verification of the dimensions

The following dimensions shall be verified:

a) for cylindrical fuel tanks, the roundness of the inner tank shall be measured and not exceed the requirements specified in 11.5.4.2 of ISO 21029-1:2004;

b) departure from a straight line of the inner tank and outer jacket shall be measured and not exceed the requirements specified in 11.5.4.3 of ISO 21029-1:2004.

6.5 Destructive and non-destructive tests of welded joints

The destructive and non-destructive tests of welded joints shall be performed and meet the requirements specified in 12.2 to 12.4 of ISO 21029-1:2004.

All welded joints of the internal pipe work between the inner tank and the outer jacket shall be subjected to 100 % non-destructive inspection. When radiographs can be interpreted, radiographic inspection shall be used. When radiographs cannot be interpreted, ultrasonic inspection shall be used. When both radiographs and ultrasonic inspection techniques cannot be used, visual inspection of welds using penetrant techniques shall be used.

6.6 Visual inspection

The welded joints on the outer surfaces of the inner tank and outer jacket shall be visually inspected. The surfaces shall not show any damage nor defects.

7 Marking and labelling

7.1 Marking method

The marking method shall not cause localized stress concentrations in either the structure of the inner tank or the outer jacket.

7.2 Inner tank markings

The inner tank shall be marked with the following information:

a) name and address of inner tank manufacturer;

b) serial number;

c) mark confirming successful routine pressure test (see 6.2).

7.3 Outer jacket markings

The outer jacket of the fuel tank shall be marked with the following information:

a) “Caution: Liquid Hydrogen”;

b) “Additional welding, milling and stamping are forbidden”;

c) Allowed orientation of the fuel tank in a land vehicle.

An identification plate marked with the following information shall be placed on the outer jacket:

a) name of the manufacturer;

b) serial number;

c) volume of the inner tank at the design temperature, expressed in litres (l);

d) MAWP of the inner tank, expressed in megapascals (MPa);

e) year and month of manufacturing in the YYYY and MM format (e.g. 2000-01);

f) ambient temperature range as per 4.3.2;

g) reference to this International Standard.

7.4 Temporary markings for first filling

A label shall be placed on the outer jacket of the fuel tank with the following information:

a) “Review the hydrogen material safety data sheets (MSDS) prior to filling with hydrogen”;

b) “Servicing of the fuel tank shall be done by trained and qualified personnel”;

c) “Air and other gases shall be removed under the following circumstances:

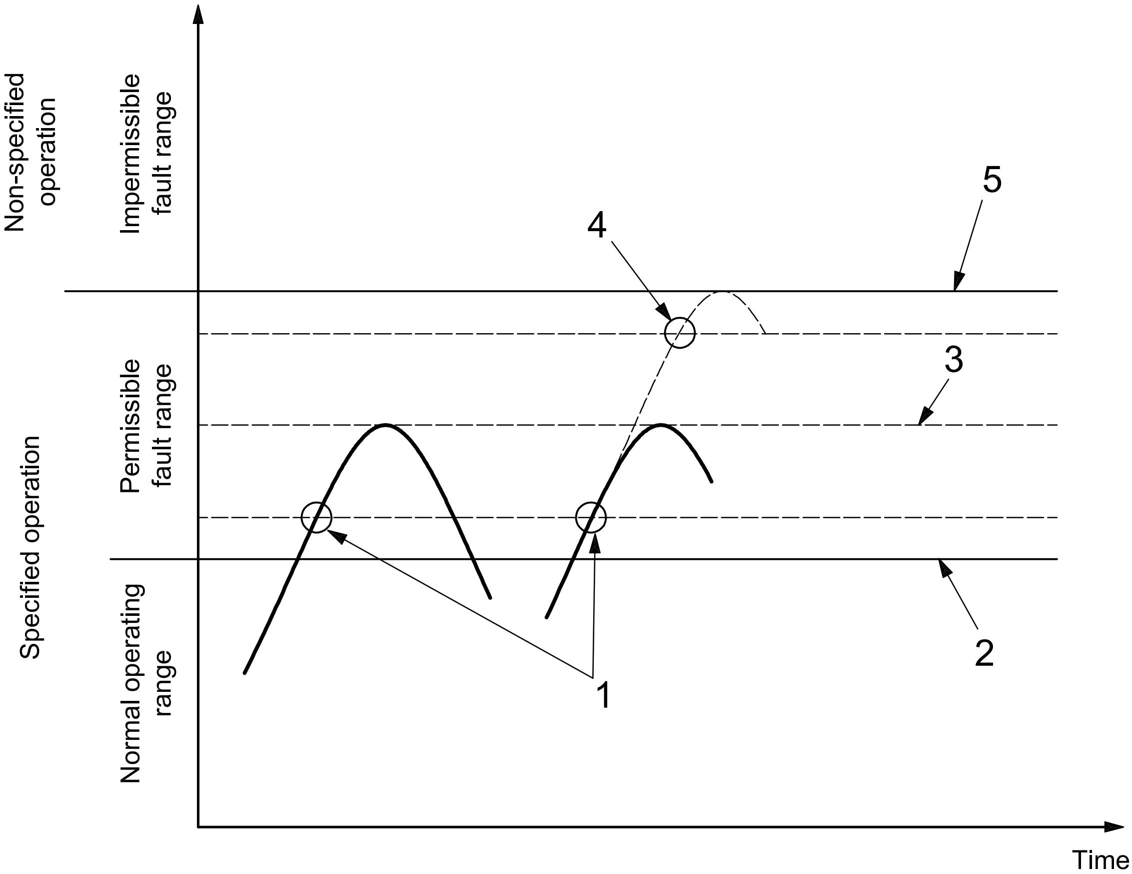
   1) before filling the fuel tank for the first time;

   2) after the fuel tank is serviced;

   3) any time the fuel tank is emptied and its pressure reduced to 0 MPa”.

Annex A
(normative)

Fuel tank operating ranges



Key

1 set pressure of primary pressure relief valve

2 maximum allowable working pressure (MAWP)

3 121 % of MAWP

4 secondary pressure relief valve responds

5 136 % of MAWP for steel inner tanks (see 4.7.2)

Figure A.1 — Fuel tank operating ranges

Annex B
(informative)

Hydrogen compatibility

Close to ambient temperature, a number of metallic materials are susceptible to hydrogen embrittlement, particularly those with a body-centred cubic lattice structure. This is a particular problem with many ferritic steels when they are subjected to mechanical stresses. Prior to being able to locally embrittle a metallic structure, hydrogen has to enter the material in atomic form. In the presence of hydrogen gas, the hydrogen molecules must first dissociate. The process prefers taking place on freshly generated metallic surfaces that are likely to form at surface defects or other stress raisers as a result of stress induced local plastic deformation processes. Furthermore, impurities such as hydrogen sulphide dissociate atomic hydrogen even more easily than molecular hydrogen.

In general, the susceptibility to hydrogen embrittlement can be lowered by:

— restricting the hardness and, therefore, the strength level of the material used to a safe level;

— lowering the level of applied stress;

— minimizing residual stresses by e.g. stress-relieving weldments, and by normalizing or fully annealing cold worked material;

— avoiding or minimizing cold plastic deformation from operations such as cold bending or forming.

In components that are subjected to frequent load cycles, all situations that can lead to local fatigue should be avoided, since hydrogen is known to significantly accelerate possible initiation and propagation of fatigue cracks in a structure.

In general, austenitic stainless steels are not susceptible or are less susceptible to hydrogen embrittlement, and are commonly used as structural materials for hydrogen equipment because of their excellent toughness at cryogenic temperatures. However, some austenitic stainless steels are not stable and can form martensite when deformed at low temperature. Martensite, being very sensitive to hydrogen embrittlement, is not recommended for use especially for equipment that will be warmed up to room temperature under hydrogen.

Annex C
(normative)

Fuel tank type tests

C.1 Inner tank burst pressure test

The design of the fuel tank shall be validated through tests specified in 10.4 of ISO 21029-1:2004.

C.2 Thermal autonomy test

C.2.1 Procedure

The inner tank shall be at the same temperature as the temperature of the liquid hydrogen. This requirement shall be deemed met if, during the previous 24 hours, the fuel tank has contained a volume of liquid hydrogen at least equal to half of the volume of the inner tank.

The fuel tank shall be filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system shall be within 10 % of the maximum allowed quantity that may be contained in the inner tank.

The length and the width of the fire shall exceed the plan dimensions of the fuel tank by 0,1 m. The average temperature of space 10 mm below the fuel tank as measured by two or more thermocouples shall be at least 590 °C. The average temperature shall remain above 590 °C for the duration of the test.

The pressure of the fuel tank at the beginning of the test shall be from 0 MPa to 0,01 MPa at the boiling point of hydrogen in the inner tank.

The lapse of time, from the moment that the average temperature first reaches 590 °C until the opening of the primary pressure relief valve, shall be measured.

Once the pressure relief valve opens, the test shall continue until the blow off of the pressure relief valve is complete.

C.2.2 Acceptance criteria

The thermal autonomy of the fuel tank, which is the lapse of time before the opening of the pressure relief valve, shall not be less than 5 min under an external fire.

The fuel tank shall not burst and the pressure inside the inner tank shall not exceed the permissible fault range of the inner tank. The secondary pressure valve shall limit the pressure inside the inner tank to the values specified in 4.7.2.

C.2.3 Test records

The test conditions, thermal autonomy and maximum pressure reached within the fuel tank during the test, shall be recorded.

C.3 Maximum filling level test

C.3.1 Procedure

The inner tank shall be brought to the same temperature as the temperature of the liquid hydrogen. This requirement shall be deemed as met if, during the previous 24 hours, the fuel tank has contained a volume of liquid hydrogen at least equal to half of the volume of the inner tank at operating pressure.

A system shall be used to measure either the mass of hydrogen or the mass flow rate at the inlet and outlet of the inner tank with an accuracy of at least 1 % of the maximum filling mass of the fuel tank under test.

The fuel tank shall be completely filled 10 times with liquid hydrogen at equilibrium with its vapour. Between each filling, at least 25 % of the liquid hydrogen shall be emptied from the fuel tank.

C.3.2 Acceptance criteria

The level of hydrogen shall never exceed the nominal maximum filling level of the inner tank as specified in 4.7.7.

C.3.3 Test records

The test conditions and the 10 maximum levels measured by the added system shall be recorded and kept on file for 10 years.

Annex D
(normative)

Accessory type tests

D.1 General requirements

Leakage tests shall be conducted with pressurized gas such as air or nitrogen containing at least 10 % helium.

Water or other fluids may be used to obtain the required pressure for hydrostatic pressure tests.

All test records shall indicate the type of test medium used, when applicable.

The test period for leakage and pressure tests shall be at least 10 min more than the response time of the pressure measuring device.

Unless otherwise stated, all tests shall be performed at an ambient temperature of 20 °C ± 5 °C.

D.2 External leakage test

The component under test shall be free from leakage at any pneumatic pressure from 0 MPa to its MAWP.

The test shall be repeated on the same component at the following conditions:

a) ambient temperature of 20 °C ± 5 °C;

b) minimum design temperature specified for the component under test or at the temperature of liquid nitrogen after 3 hours of conditioning at this temperature;

c) maximum design temperature specified for the component under test after 3 hours of conditioning at this temperature.

In order to perform this test, the component under test shall be dried and connected to a pneumatic source of pressure. A positive shut-off valve pressure limiting control and a pressure gauge having a pressure range of not less than 1,5 times nor more than 2 times the test pressure shall be installed in the pressure supply piping. The pressure gauge shall be installed between the positive shut-off valve and the sample under test. The accuracy of the pressure gauge shall not be less than 1 % of the test pressure range.

Throughout the test, the sample shall be checked for leaks. The leakage rate shall be less than 2 cm^3/h at 20 °C and 101,325 kPa per accessory. If a flow meter is used, it shall be capable of measuring, for the test fluid employed, the maximum leakage rate permitted with an accuracy of ± 1 %.

D.3 Seat leakage test

The seat leakage test shall be conducted with the inlet of the sample valve connected to a pneumatic source of pressure, the valve in the closed position, and with the outlet open. A positive shut-off valve and a pressure gauge having a pressure range of not less than 1,5 times and not more than 2 times the test pressure shall be installed in the pressure supply piping. The pressure gauge shall be installed between the positive shut-off valve and the sample under test. The accuracy of the pressure gauge shall not be less than 1 % of the test pressure range.

In order to perform the test, the pressure shall be gradually increased to the MAWP of the component under test. Observations for leakage shall be made with the open outlet submerged in water or with a flow meter installed on the inlet side of the valve under test.

If leakage is measured with the open outlet submerged in water, no detectable leak shall be observed.

If a flow meter is used, it shall be capable of measuring, for the test fluid employed, the maximum leakage rate permitted with an accuracy of 0,02 cm^3/h at 20 °C and 101,325 kPa. The maximum leakage rate shall be less than 2 cm^3/h at 20 °C and 101,325 kPa.

D.4 Pressure test

The component under test shall withstand without any visible evidence of leak or deformation a test pressure of 1,5 times its MAWP with the openings plugged or capped. The pressure shall then be increased from 1,5 to 3 times the MAWP. The component under test shall not show any visible evidence of rupture or cracks.

The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge, having a pressure range of not less than 1,5 times nor more than 2 times the higher test pressure. The accuracy of the gauge shall not be less than 1 % of the higher test pressure.

D.5 Endurance test (continuous operation)

The component under test shall be securely connected to a pressurized source of dry air or nitrogen and subjected to 20 000 cycles. A cycle shall consist of one opening and one closing of the component within a period of not less than 10 s ± 2 s. During the off cycle, the downstream pressure of the test fixture shall be allowed to decay to 50 % or less of the MAWP of the component.

The component under test shall be operated for 2 % of the specified number of cycles at its MAWP and at its maximum design temperature after 3 hours conditioning at this temperature. After the completion of the specified number of cycles and while still at the maximum design temperature, the component shall be subjected to the tests specified in D.2 and D.3 and meet the requirements therein.

The component under test shall be operated for 2 % of the specified number of cycles at its MAWP and at its minimum design temperature or at the temperature of liquid nitrogen after 3 hours conditioning at this temperature. After the completion of the specified number of cycles and while still at the minimum design temperature, the component shall be subjected to the tests specified in D.2 and D.3 and meet the requirements therein.

The component under test shall be operated for 96 % of the specified number of cycles at its MAWP and an ambient temperature of 20 °C ± 5 °C.

Immediately after being subjected to the number of operation cycles specified for that component, the component shall be subjected to the tests specified in D.2 and D.3 at an ambient temperature of 20 °C ± 5 °C and meet the requirements therein.

D.6 Corrosion resistance test

Metallic components shall be submitted to a 144-hour salt spray test in accordance with ISO 9227 with all connections closed. After the test, the component shall be subjected to the tests specified in D.2 and D.3 and meet the requirements therein.

Copper and copper alloy parts of the component shall be submitted to a 24-hour immersion in ammonia in accordance with ISO 6957 (see Annex A for the pH-value at moderate corrosiveness and high safety) with all connections closed. After the test, the component shall be subjected to the tests specified in D.2 and D.3 and meet the requirements therein.

D.7 Resistance to dry-heat

The test shall be done in compliance with 3.1 of ISO 188:1998. The test piece shall be exposed to air at a temperature equal to the component maximum design temperature for 168 hours.

The change in tensile strength shall not exceed 25 %. The change in ultimate elongation shall not exceed the following values:

a) maximum increase: 10 %;

b) maximum decrease: 30 %.

D.8 Ozone ageing test

The test shall be performed in compliance with ISO 1431-1. The test piece shall be stressed to 20 % elongation and exposed to air at 40 °C with an ozone concentration of 50 µl/l during 120 hours. The test piece shall show no evidence of cracking.

D.9 Temperature cycle test

The component under test shall be submitted to 24 temperature cycles. Each temperature cycle shall range from the minimum design temperature up to the maximum design temperature and back to the minimum temperature in a period of about 4 hours. At the levels of maximum and minimum design temperature, the pressure shall be increased to its MAWP and left constant for at least 10 min. The component under test shall meet the leak requirements specified in D.2.

After the completion of the specified number of temperature cycles, the component shall be subjected to the tests specified in D.2 and D.3 and meet the requirements therein.

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