SGS 3 - 8

BMW proposal for

Technical requirements concerning

LIQUID HYDROGEN STORAGE SYSTEMS

for the use in hydrogen powered road vehicles

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1. SCOPE

1.1.1. The scope of this document is to define the requirements and qualification tests for Liquid Hydrogen Storage Systems (LHSS) in hydrogen powered road vehicles.

1.1.2. A LHSS regularly consists of the liquefied hydrogen containment vessel (container), pressure relief devices (PRDs), shut-off devices, a boil-off system and all components, fittings and fuel lines between the container and these devices.

1.1.3. A hypothetical LHSS with its main components is shown in figure 1.

1.1.4. The requirements for the vehicle itself or other hydrogen components than the storage system (e.g. fuel handling system, hydrogen fuel cell, hydrogen internal combustion engine…) are beyond the scope of this document.

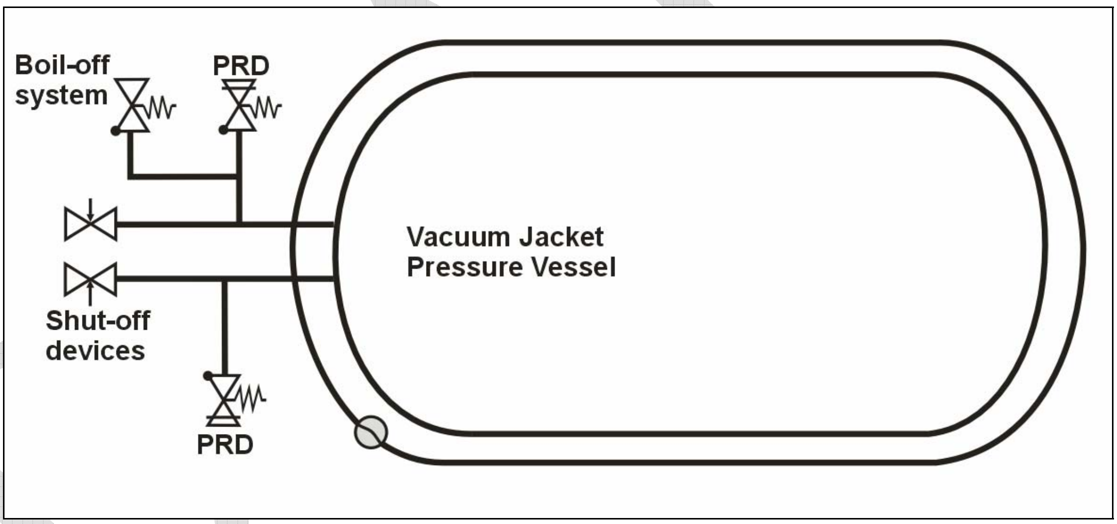

figure 1 – liquid hydrogen storage system

2. DEFINITIONS

2.1. "Automatic valve" means a valve that is operated by a controllable actuator (e.g. pneumatic or electric actuator)

2.2. "Boil-off system" means a system that in normal conditions vents the boil-off before the pressure relief device of the container(s) opens.

2.3. "Burst pressure" means the pressure that causes the bursting of a pressure vessel subjected to a constant increase of pressure during a destructive test.

2.4. "Container" means any system used for the storage of cryogenic hydrogen.

2.5. "Equipment of the container" means all devices that are fixed directly to the inner tank or outer jacket of the container.

2.6. "Flexible fuel line" means flexible tubing or a hose through which hydrogen flows.

2.7. "H_2" means hydrogen.

2.8. "Hydrogen component" means a component which is in direct contact with hydrogen or which forms part of a system installed because of the use of hydrogen.

2.9. "Hydrogen conversion system" means any system designed for the consumption of hydrogen (e.g. fuel cell, hydrogen combustion engine, boil-off converter)

2.10. "Hydrogen system" means the complete assembly of hydrogen components and connecting parts installed on motor vehicles using hydrogen excluding the conversion system(s).

2.11. "Impermissible fault range" of a process variable means the range within which an unwanted event is to be expected, e.g. the corresponding pressure where plastic deformation or bursting occurs.

2.12. "Inner tank" means the part of the container that contains the cryogenic hydrogen.

2.13. "LH_2" means liquefied hydrogen.

2.14. "Maximum Allowable Working Pressure (MAWP)" means the 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.

2.15. "Normal operating range" of a process variable means the range planned for its values. In the case of inner tanks, the normal operating range of the inner tank pressure is between 0 MPa and the set pressure of the primary safety relief device which is lower or equal to the Maximum Allowable Working Pressure (MAWP) of the inner tank.

2.16. "Outer jacket" means the part of the container that encases the inner tanks and its insulation system.

2.17. "Outer pressure" means the pressure acting on the convex side of the inner tank or outer jacket, e.g. in case of vacuum inside the inner tank and/or the outer jacket.

2.18. "Permissible fault range" of a process variable means the range between the normal operating range and the impermissible fault range (see Figure 1).

2.19. "Pressure" means gauge pressure against atmospheric pressure, unless otherwise stated.

2.20. "Pressure relief device" means a device which prevents a pre-determined pressure from being exceeded (e.g. Maximum Allowable Working Pressure (MAWP) of a component) by releasing the pressure.

2.21. "Rm" means minimum ultimate tensile strength.

2.22. "Rp" means minimum yield strength.

2.23. "Rigid fuel line" means a tubing that has not been designed to flex in normal operation and through which hydrogen flows.

2.24. "Safety device" means a device that ensures safe operation within the normal operating range or the permissible fault range of the system.

2.25. "Shut-off device" means a device that is capable of preventing hydrogen flow from the container to other hydrogen components downstream of the device.

2.26. "Test pressure" (P_{test}) means the pressure that a component is subjected to during acceptance testing.

3. GENERAL REQUIREMENTS

3.1. General provisions

3.1.1. The hydrogen components shall function in a correct and safe way as specified in this regulation. They shall reliably withstand the electrical, mechanical, thermal and chemical operating conditions.

3.1.2. Those parts of the liquid hydrogen storage system whose correct and safe functioning is liable to be influenced by hydrogen or high pressure shall be submitted to the relevant provisions and test procedures described in this regulation.

3.1.3. The requirements of this regulation shall take precedence over the requirements of any standards referred to in this regulation.

3.1.4. If a test method other than those specified in this regulation is used, its equivalence shall be proved.

3.2. Material and insulation

3.2.1. Materials of the components which are in contact with cryogenic temperatures shall be compatible with cryogenic temperatures according to EN 1252-1:1998/AC:1998 or equivalent ISO Standard.

3.2.2. Materials of the components which are in contact with hydrogen shall be compatible with it according to ISO 11114-4:2005.

3.2.3. In hydrogen components that are subjected to frequent load cycles, conditions that can lead to local fatigue and the initiation and propagation of fatigue cracks in the structure shall be avoided.

3.2.4. The insulation of the components shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is provided for collecting and vaporizing the liquefied air. Then the materials of the components nearby shall be compatible with an atmosphere enriched with oxygen according to EN 1797:2001 or equivalent ISO Standard.

3.3. Temperature ranges

3.3.1. The operating temperatures of the hydrogen system should be at least -40°C to +80°C.

3.3.2. The internal temperature, taken into account for cryogenic hydrogen components should be -253 °C to +80°C, unless otherwise specified by the vehicle manufacturer.

3.4. Pressure ranges

3.4.1. For all hydrogen components of the liquid hydrogen storage system, a Maximum Allowable Working Pressure (MAWP) shall be defined equal to the maximum pressure the component is subjected to within normal operation.

3.4.2. In case of steel inner tanks, the lower limit of the impermissible fault range shall correspond to a pressure higher than 150 per cent of the Maximum Allowable Working Pressure (MAWP). For other materials and for any other hydrogen component within the liquid hydrogen storage system an equivalent level of safety is to be applied.

4. PROVISIONS REGARDING THE HYDROGEN CONTAINER AND ITS EQUIPMENT

4.1. Design provisions

4.1.1. The design of the inner tank and the outer jacket shall be done according to the design rules of EN 1251-2:2000 or equivalent ISO Standard.

4.1.2. The design validation of the container by calculation shall be done in accordance with EN 1251-2:2000 or equivalent ISO Standard. Other regulations may be applied if they are at least equivalent.

4.1.3. Unless indicated otherwise the general tolerances of ISO 2768-1:1989 shall apply.

4.1.4. The design temperature of the inner tank (including inner tank burst disc, if applicable) and the outer jacket shall be 20°C.

4.1.5. For all other equipment the design temperature is the lowest respectively the highest possible operating temperature.

4.1.6. The thermal stresses by operating conditions like filling or withdrawal or during the cooling down processes shall be considered.

4.2. Mechanical stresses

The following mechanical stresses shall be considered:

4.2.1. <u>Inner tank</u>

4.2.1.1. The test pressure:
The inner tank shall resist the test pressure P_{test}:

$$P_{test} = 1.3\ (MAWP + 0.1\ MPa)$$

with MAWP: Maximum Allowable Working Pressure of the inner tank in MPa

4.2.1.2. Outer pressure:
If an operating mode of the inner tank and its equipment under vacuum is possible, the inner tank and its equipment shall resist an outer pressure of 0.1 MPa.

4.2.2. <u>Outer jacket</u>

4.2.2.1. The outer jacket shall resist the Maximum Allowable Working Pressure (MAWP), which is the set pressure of its safety device.

4.2.2.2. The outer jacket shall resist an outer pressure of 0.1 MPa.

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

4.2.3. <u>Outer supports</u>

The outer supports of the full container shall resist the accelerations named in paragraph 4.2.6 of this regulation without rupture, in which case the allowable stress in the support elements shall not exceed (calculated according linear stress model):

$$\sigma \leq 0.5\ R_m$$

4.2.4. <u>Inner supports</u>

The inner supports of the full container shall resist the accelerations named in paragraph 4.2.6 of this regulation without rupture, in which case the allowable stress in the support elements shall not exceed (calculated according linear stress model):

$$\sigma \leq 0.5\ R_m\ .$$

4.2.5. The requirements of paragraphs 4.2.3 and 4.2.4 do not apply if it can be demonstrated that the tank may support the accelerations named in paragraph 4.2.6 of this regulation without any leak on the inner tank and all the different pipes upstream shut-off devices, boil-off system and PRDs.

4.2.6. Unless otherwise specified by the vehicle manufacturer, the hydrogen container(s) including the safety devices affixed at it must be mounted and fixed so that the specified following accelerations can be absorbed without damage of the safety related parts when the hydrogen containers are full.

Vehicle of categories M1 and N1:
20 g in the direction of travel
8 g horizontally perpendicular to the direction of travel

Vehicles of categories M2 and N2:
10 g in the direction of travel
5 g horizontally perpendicular to the direction of travel

Vehicles of categories M3 and N3:
6.6 g in the direction of travel
5 g horizontally perpendicular to the direction of travel

4.2.7. The proof of the dimensioning of the supports of the container can be done either by calculation or by experiment, e.g. crash tests.

4.3. Chemical compatibility

4.3.1. The materials of the container and its equipment shall be compatible with:
- hydrogen, if the parts are in contact with
- the atmosphere, if the parts are in contact with
- other media if the parts are in contact with (i.e. coolant, etc.)

4.4. Materials

4.4.1. The manufacturer of the materials shall provide:
- the appropriate equipment for manufacturing and testing
- the appropriate procedures for manufacturing
- the competent personnel for manufacturing and testing
- the appropriate quality assurance and documentation to ensure the quality and the traceability of the material

4.4.2. The materials shall be composed, manufactured and further treated in a manner that:
- the finished products show the required mechanical properties
- the finished products which are used for pressurised components and are in contact with hydrogen resist the thermal, chemical and mechanical stresses that they may be subjected to.

4.4.3. <u>Characteristics</u>

4.4.3.1. Materials used at low temperatures shall follow the toughness requirements of EN 1252-1:1998/AC1998 or equivalent ISO Standard. For non-metallic materials low temperature suitability shall be validated by an experimental method, taking into account service conditions.

4.4.3.2. The materials used for the outer jacket shall ensure the integrity of the insulation system, and their elongation at fracture in a tensile test shall be at least 12 per cent at liquid nitrogen temperature.

4.4.3.3. A corrosion allowance is not required for the inner tank. A corrosion allowance is not required on other surfaces if they are adequately protected against corrosion.

4.4.3.4. The filler materials shall be compatible with the parent material so as to form welds with properties equivalent to those specified for the parent material for all temperatures that the material may encounter.

4.4.3.5. The container manufacturer shall obtain and provide chemical cast analysis and mechanical properties certificates of the material in respect of the steels or other materials used in the construction of the parts subject to pressure. In case of metallic materials the certificate must be at least type 3.1.B according to EN 10204:1991/A1:1995 or equivalent ISO Standard. In case of non-metallic materials the certificate must be of equivalent type.

4.5. Manufacturing and mounting of the container

4.5.1. The manufacturer of the containers or parts of it shall provide:

- the appropriate equipment for manufacturing and testing
- the appropriate procedures for manufacturing
- the competent personnel for manufacturing and testing
- a manufacturing and inspection plan
- the appropriate quality assurance and documentation to ensure the quality and the traceability of the parts and materials

4.5.2. Manufacturing operations (e.g. forming and heat treatment, welding) shall be carried out according to EN 1251-2:2000 or equivalent ISO Standard.

4.5.3. The inspections and the testing of the internal pipe work between the inner tank and the outer jacket: all welded joints of the pipe work shall be subject to 100 per cent non destructive inspection, where ever possible by radiographic inspection, alternatively ultrasonic test, penetration test, helium leakage test etc.

4.5.4. The number of joints should be minimized. Joints shall not be permitted within the void between the inner tank and the outer jacket unless they are welded or glued.

4.5.5. The equipment of the container shall be mounted in a way that the system and its components function in a correct and safe way and are gas tight.

4.5.6. The container shall be cleaned and dried before operation according to EN 12300:1998 or equivalent ISO Standard.

4.6. Applicable test procedures

4.6.1. For type approval/product qualification, the container and its equipment shall be subjected to the tests, marked in table 1. The tests shall be performed according to chapter 6 of this regulation.

CONTAINER TEST
Pressure Test
Leak Test
Inspection of dimensions & welding seams
Inner tank burst test
Bonfire test

table 1 –applicable tests for the container

4.6.2. Inspection openings are not required in the inner or outer jacket.

5. PROVISIONS REGARDING OTHER COMPONENTS

This chapter applies to pressure relief devices (PRDs), hydrogen valves (shut-off device, boil-off system) and flexible fuel lines within the liquid hydrogen storage system, if they do not belong to the direct equipment of the container.

5.1. Provisions regarding pressure relief devices

5.1.1. The pressure relief devices shall ensure that the components of the liquid hydrogen storage system are not subjected to unwanted overpressure.

5.1.2. The primary pressure relief device shall limit the pressure in the liquid hydrogen storage system to not more than 110 per cent of the Maximum Allowable Working Pressure (MAWP).

5.1.3. The secondary pressure relief device shall be installed to ensure that the pressure in the liquid hydrogen storage system cannot under any circumstances exceed the permissible fault range of the inner tank. The secondary pressure relief device shall not operate below 110 per cent of the set pressure of the primary pressure relief device.

5.1.4. The relevant pressure ranges in case of steel inner tanks are shown in figure 2:

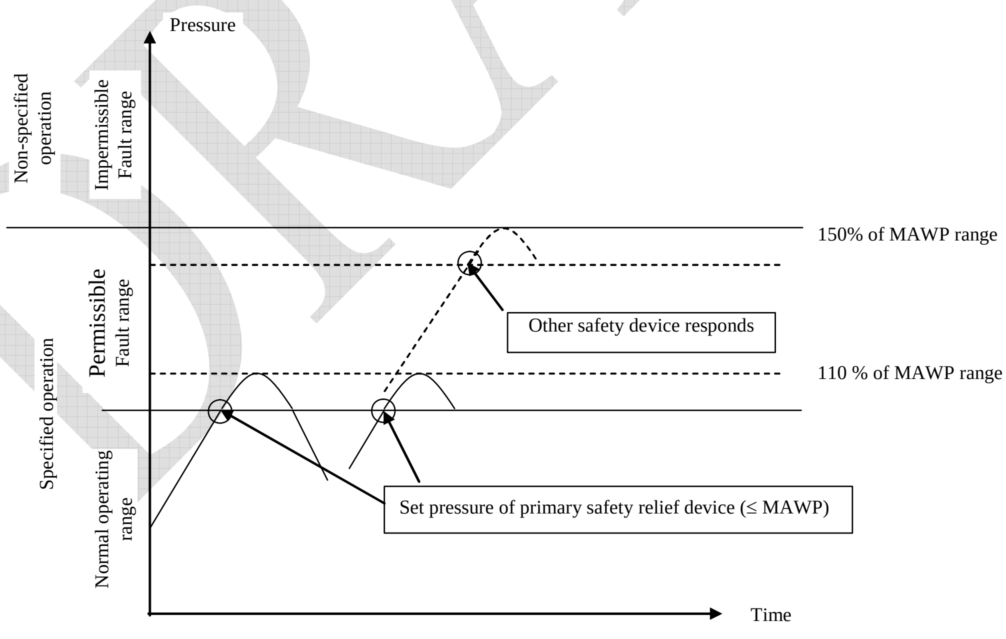

figure 2 – pressure ranges of a steel inner tank

5.1.5. The two pressure relief devices may be connected to the inner tank by the same fuel line.

5.1.6. If a safety valve is used as a pressure relief device, it shall be designed, manufactured and controlled in accordance with EN 13648-1:2002 or equivalent ISO Standard.

5.1.7. If a burst disc is used as pressure relief device, it shall be designed, manufactured and controlled in accordance with EN 13648-2:2002 or equivalent ISO Standard.

5.1.8. If safety valves or burst discs are used as pressure relief devices, the sizing of the discharge capacity shall be done in accordance with EN 13648-3:2000 or equivalent ISO Standard.

5.1.9. In case a pressure relief device is a burst disc and is installed within the inner tank, an appropriate exhaust vent in the outer jacket is required.

5.1.10. In case the first pressure relief device is a safety valve or burst disc, the requirements of paragraph 5.1.6 and 5.1.7 shall also apply for this component.

5.1.11. If safety valves or burst discs are used as pressure relief devices, they shall be subjected to qualification tests laid down in paragraph 5.5.1 of this regulation.

5.1.12. If a pressure relief device is not a safety valve or burst disc, requirements and qualification tests that give an equivalent level of safety have to be defined.

5.2. Provisions regarding shut-off devices

5.2.1. All hydrogen lines connected to the inner tank, except the lines to the boil-off system and the pressure relief devices, shall be secured with shut-off devices.

5.2.2. In closed position, these devices shall be capable of preventing hydrogen flow from the container to other hydrogen components downstream of the device.

5.2.3. The shut-off device shall be closed idle (fail-safe) and shall close in the event of a crash or of a break of the fuel supply line(s).

5.2.4. In the event that the container is displaced, the first isolating device and if applicable, the line connecting it to the container shall be protected in such a manner that the shut-off function remains operational and the connection between the device and the container cannot be ruptured.

5.2.5. If automatic valves are used as shut-off devices, they shall be subjected to the qualification tests laid down in paragraph 5.5.1 of this regulation.

5.2.6. If automatic valves are used as shut-off devices, the number of operation cycles shall be assumed to be 20.000, unless otherwise specified by the vehicle manufacturer.

5.2.7. If the shut-off device is not an automatic valve, requirements and qualification tests that give an equivalent level of safety have to be defined.

5.3. Provisions regarding the boil-off system

5.3.1. Within the liquid hydrogen storage system, a boil-off system shall be installed, that under normal operating conditions limits the tank pressure below the initial response pressure of the primary pressure relief device.

5.3.2. If a hydrogen valve is used as boil-off system, it shall be subjected to the qualification tests laid down in paragraph 5.5.1 of this regulation.

5.3.3. If a hydrogen valve is used as boil-off devices, the number of operation cycles shall be assumed to be 6.000, unless otherwise specified by the vehicle manufacturer.

5.3.4. If the boil-off system is not a hydrogen valve, requirements and qualification tests that give an equivalent level of safety have to be defined.

5.3.5. Unless the storage system is designed for 100% liquid filling level, a system shall be provided within the vehicle that under normal operation conditions prevents the container from being overfilled. This system may work in conjunction with the refuelling station and has to ensure, that the filling process does not lead to any pressure relief device coming into operation irrespective of time passed during/after the filling process. The filling process shall not lead to operating conditions the boil-off system is not designed for and therefore cannot handle.

5.4. Provisions regarding the hydrogen lines within the storage system

5.4.1. Within lines incorporating pressure relief devices, no isolating device shall be installed between the protected component and the pressure relief device.

5.4.2. The lines before and behind the pressure relief devices shall not impede their function.

5.4.3. The design, manufacturing and control of cryogenic flexible fuel lines shall be in accordance with EN 12434:2000 or equivalent ISO Standard.

5.4.4. If flexible fuel lines are used within the LHSS, they shall be subjected to the qualification tests laid down in paragraph 5.5.1 of this regulation.

5.5. Applicable test procedures

5.5.1. For product qualification, the components shall be subjected to the tests, marked in table 2. The tests shall be performed according to chapter 7 of this regulation.

COMPONENT TEST	PRDs	Valves	Flexible Lines	Comments
Pressure Test	√	√	√	
External Leakage Test	√	√	√	
Seat Leakage Test	√	√		PRD only if it is a valve
Endurance Test		√		
Operational Test	√			PRD only if it is a valve
Corrosion Resistance Test	√	√	√	only for metallic parts outside a gas tight housing
Resistance to dry heat test	√	√	√	only for non-metallic parts
Ozone ageing test	√	√	√	only for non-metallic parts
Temperature Cycle Test	√	√	√	only for non-metallic parts
Pressure Cycle Test			√	

table 2 – applicable tests for certain hydrogen component

6. TEST PROCEDURES FOR THE CONTAINER

6.1. Pressure test

6.1.1. The inner tank and the pipe work situated between the inner tank and the outer jacket shall withstand an inner pressure test at room temperature any suitable media, according to the following requirements.
The test pressure p_{test} shall be:

$$p_{test} = 1.3\ (MAWP + 0.1\ MPa)$$

with MAWP: Maximum Allowable Working Pressure of the inner tank in MPa.

6.1.2. The pressure test is to be performed before the outer jacket is mounted.

6.1.3. The pressure in the inner tank shall be increased at an even rate until the test pressure is reached.

6.1.4. The inner tank must remain under the test pressure at least for 10 minutes to establish that the pressure is not reducing.

6.1.5. After the test the inner tank must not show any signs of visible permanent deformation or visible leaks.

6.1.6. Any inner tank tested which does not pass the test because of permanent deformation shall be rejected and shall not be repaired.

6.1.7. Any inner tank tested which does not pass the test because of leakage may be accepted after repair and retesting.

6.1.8. In case of hydraulic test, upon completion of this test, the container shall be emptied and dried until the dew point inside the container is - 40 °C, according to EN 12300:1998 or equivalent ISO Standard.

6.1.9. A test report shall be drawn up and the inner tank shall be marked by the inspection departments if accepted.

6.2. Leak test

6.2.1. The hydrogen container shall be leak tested to verify that it is gas tight.

6.3. Inspection of the dimensions and welding seams

6.3.1. For cylindrical container(s), the roundness of the inner tank shall be verified, according to EN 1251-2:2000, 5.5 or equivalent ISO Standard.

6.3.2. The departure from a straight line of the inner and outer jacket shall be verified according to EN 1251-2:2000, 5.5 or equivalent ISO Standard.

6.3.3. The welding seams shall be tested according to EN 1251-2:2000 or equivalent ISO Standard.

6.3.4. The welding seams and the inner and outer surfaces of the inner and outer jackets of the container shall be inspected visually. The surfaces shall not show any critical damages or defaults.

6.4. Inner tank burst test

6.4.1. Criteria

6.4.1.1. An inner tank not integrated in its outer jacket and not insulated shall withstand a burst test.

6.4.1.2. The burst pressure shall be at least equal to the burst pressure used for the mechanical calculations. For steel tanks that is to say:
- either the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 3.25;
- or the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by R_m / R_p.

6.4.1.3. At the Maximum Allowable Working Pressure (MAWP), the principal dimensions (perimeter, length, etc.) shall not be modified more than 1 per cent.

6.4.1.4. Once the test is completed the volume of the tank shall have increased by more than 8 per cent.

6.4.1.5. The performance of hydrogen containers made from materials other than steel, shall be demonstrated to be equivalent to these requirements according to existing international standards.

6.4.2. Procedure

6.4.2.1. The test tank shall be representative of the design and the manufacturing of the type to be qualified.

6.4.2.2. The test shall be a hydraulic test.

6.4.2.3. The tube and piping may be modified to enable the test (purge of dead volume, introduction of the liquid, closing of non used pipes, etc.)

6.4.2.4. The tank shall be filled with water. The pressure will be increased at a constant rate not exceeding 0.5 MPa/min until burst. When the Maximum Allowable

Working Pressure (MAWP) is reached there will be a at least ten minute wait period at constant pressure so that the deformation of the tank shall be checked in accordance with paragraph 6.4.1.3.

6.4.2.5. A system will enable to look at possible deformations.

6.4.2.6. The pressure shall be recorded or written during the entire test.

6.4.3. Results

6.4.3.1. The results shall be presented in a test summary, and shall include the following data for each container as a minimum:
a) The test conditions
b) The bursting pressure

6.5. Bonfire test

6.5.1. Criteria

6.5.1.1. The tank shall not burst and the pressure inside the inner tank shall not exceed the permissible fault range of the inner tank, according to paragraph 3.4.2 of this regulation.

6.5.1.2. In this test, the secondary pressure relief device may be activated, to limit the pressure inside the tank below the upper limit of the permissible fault range. According to paragraph 5.1.3 of this regulation, it shall not operate below 110 per cent of the set pressure of the primary pressure relief device.

6.5.2. Procedure

6.5.2.1. The test tank shall be representative of the design and the manufacturing of the type to be qualified.

6.5.2.2. Its manufacturing is completely finished and it is mounted with all its equipment.

6.5.2.3. The tank has already been cooled down and the inner tank is at the same temperature as the liquid hydrogen. The tank has contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner tank.

6.5.2.4. The tank is filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system shall be at least half of the maximum allowed quantity that may be contained in the inner tank.

6.5.2.5. Place the container in a horizontal position approximately 100 mm above a uniform fire source with a length of 1.65 m. The arrangement of the fire shall be recorded in sufficient detail to ensure the rate of heat input to the container is reproducible. Any failure or inconsistency of the fire source during a test shall invalidate the result.

6.5.2.6. The container shall be positioned centrically above the fire source.

6.5.2.7. Metallic shielding shall be used to prevent direct flame impingement on container valves, fittings, or pressure relief devices. The metallic shielding shall not be in direct contact with the pressure relief devices. Any failure during the test of a valve, fitting or tubing that is not part of the intended protection system for the design shall invalidate the result.

6.5.2.8. Surface temperatures shall be monitored by at least three thermocouples located along the bottom of the container and spaced not more than 0.75 m apart. Metallic shielding shall be used to prevent direct flame impingement on the thermocouples. Alternatively, thermocouples may be inserted into blocks of metal measuring less than 25 mm x 25 mm x 25 mm.

6.5.2.9. The fire source shall provide direct flame impingement on the container surface across its entire diameter immediately following ignition

6.5.2.10. Thermocouple temperatures and the container pressure shall be recorded at intervals of $\leq$ 10 seconds during the test.

6.5.2.11. Within 5 minutes of ignition and for the remaining duration of the test the temperature of at least one thermocouple shall indicate at least 590 °C.

6.5.2.12. Once the safety device(s) open, the test shall continue until the blow off of the safety device has finished.

6.5.3. <u>Results</u>

6.5.3.1. The results shall be presented in a test summary, and shall include the following data for each container as a minimum:
a) The test conditions
b) The elapsed time from ignition of the fire to the start of venting through the pressure relief device(s)
c) The maximum pressure and time of evacuation until a pressure $\leq$ 1.0 MPa is reached

6.6. Crash test

6.6.1. A crash test or equivalent component test shall be performed, if calculations are not sufficient to determine and verify the design criteria of the container jackets or supports.

6.6.2. If a crash test is performed it shall be in accordance with paragraph 4.2.6 of this regulation.

7. TEST PROCEDURES FOR OTHER COMPONENTS

7.1. General provisions

7.1.1. Leakage tests may be conducted with a suitable pressurized gas other than hydrogen. In this case, the rate of hydrogen gas leakage has to be calculated, based on the characteristics of the used test gas.

7.1.2. Water or another fluid may be used to obtain the required pressure for pressure test.

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

7.1.4. The test period for leakage and pressure tests shall be not less than 3 minutes more than the response time of the sensor.

7.1.5. All tests shall be performed at a temperature of 20°C ± 5°C, unless otherwise stated.

7.1.6. The different components shall be correctly dried before leak test.

7.2. Pressure test

7.2.1. A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 1.5 times its MAWP with the outlets of the high pressure part plugged. The pressure shall then be increased from 1.5 to 3 times the MAWP. The component shall not show any visible evidence of rupture or cracks.

7.2.2. The pressure supply system shall be equipped with a shut-off valve and a pressure gauge, having a pressure range of not less than 1.5 times nor more than 2 times the test pressure and the accuracy of the gauge shall be 1 per cent of the pressure range.

7.2.3. For components requiring a leakage test, this test shall be performed prior to the pressure test.

7.3. External leakage test

7.3.1. A component shall be free from leakage through stem or body seals or other joints, and shall not show evidence of porosity in casting at any pneumatic pressure between zero and its Maximum Allowable Working Pressure (MAWP).

7.3.2. The test shall be performed on the same equipment at the following conditions:

7.3.2.1. at a temperature of 20 °C ± 5 °C;

7.3.2.2. at the minimum operating temperature or at liquid nitrogen temperature after 3 hours conditioning at this temperature;

7.3.2.3. at the maximum operating temperature after 3 hours conditioning at this temperature.

7.3.3. During this test the equipment under test will be connected to a source of pneumatic pressure. A shut-off valve and a pressure gauge having a pressure range of not less than 1.5 times nor more than 2 times the test pressure are to be installed in the pressure supply piping and the accuracy of the gauge shall be 1 per cent of the pressure range. The pressure gauge is to be installed between the shut-off valve and the sample under test.

7.3.4. Throughout the test, the sample will be tested for leakage, with a surface active agent without formation of bubbles or measured with a leakage rate less than $2.8 \cdot 10^{-3}$ mbarl/s.

7.4. Seat leakage test

7.4.1. The following tests for seat leakage are to be conducted on samples which have previously been subjected to the external leakage test of paragraph 7.3 of this annex.

7.4.2. Seat leakage tests shall be conducted with the inlet of the sample valve connected to a source of pneumatic pressure, the valve in the closed position, and with the outlet open.

7.4.3. A shut-off valve and a pressure gauge having a pressure range of not less than 1.5 times and not more than twice the test pressure are to be installed in the pressure supply piping and the accuracy of the gauge shall be 1 per cent of the pressure range.

7.4.4. The pressure gauge is to be installed between the shut-off valve and the sample under test. While under the applied test pressure corresponding to the MAWP, observations for leakage are to be made with the open outlet submerged in water or by a flow meter installed on the inlet side of the valve under test.

7.4.5. The flow meter shall be capable of indicating, for the test fluid employed, the maximum leakage flow rates permitted within an accuracy of +/-1 per cent.

7.4.6. The seat of the valve, when in the closed position, shall not leak at a rate exceeding $1 \cdot 10^{-2}$ mbar l/s at any pneumatic pressure between zero and MAWP.

7.5. Endurance test

8.5.1. A hydrogen carrying component shall be capable of conforming to the applicable leakage test requirements of paragraphs 7.3 and 7.4, after being subjected to the number of operation cycles specified for that component (see paragraph 5.2.6 and 5.3.3).

8.5.2. The appropriate tests for external leakage and seat leakage, as described in paragraphs 8.3 and 8.4 are to be conducted immediately following the endurance test.

8.5.3. The component shall be securely connected to a pressurized source of dry air or nitrogen and subjected to the number of cycles specified for that component in paragraph 8.1.7. A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds.

8.5.4. Unless otherwise specified by the vehicle manufacturer, the component shall be operated through

- 96 per cent of the total cycles at a temperature of 20 °C ± 5 °C
- 2 per cent of the total cycles at the maximum material temperature after 3 hours conditioning at this temperature
- 2 per cent of the total cycles at the minimum material temperature but not less than the temperature of liquid nitrogen after 3 hours conditioning at this temperature

and at the MAWP of the component.

8.5.5. During the off cycle the downstream pressure of the test fixture should be allowed to decay to 50 per cent of the MAWP of the component.

8.5.6. The component shall comply with paragraphs 8.3 and 8.4 of this regulation at the appropriate maximum material temperature at the completion of the high temperature cycles.

8.5.7. The component shall comply with paragraphs 8.3 and 8.4 of this regulation at the appropriate minimum material temperature at the completion of the low temperature cycles.

7.6. Operational test

7.6.1. If the pressure relief device is a valve, the operational test has to be carried out in accordance with EN 13648-1:2002 or EN 13648-2:2002 or equivalent ISO Standard. The specific requirements of the standard are applicable.

7.7. Corrosion resistance

7.7.1. Metallic hydrogen containing components shall comply with the leakage tests mentioned in paragraphs 7.3 and 7.4, if applicable, after being submitted to 144 hours salt spray test according to DIN 50021:1998, ISO 9227:1990 or IEC 60068-2-52:1996 with all connections closed.

7.7.2. A copper or brass hydrogen containing component shall comply with the leakage tests mentioned in paragraphs 7.3 and 7.4 after being submitted to 24 hours immersion in ammonia according to DIN 50916-2:1985 or ISO 6957:1988 with all connections closed.

7.8. Resistance to dry heat test

7.8.1. The test has to be done in compliance with ISO 188:1998. The test piece has to be exposed to air at a temperature equal to the maximum operating temperature for 168 hours. The change in tensile strength shall not exceed + 25 per cent. The change in ultimate elongation shall not exceed the following values:

- maximum increase 10 per cent,
- maximum decrease 30 per cent.

7.9. Ozone ageing

7.9.1. The test has to be in compliance with ISO 1431-1:1989. The test piece, which has to be stressed to 20 per cent elongation, shall be exposed to air at 40 °C with an ozone concentration of 50 parts per hundred million during 120 hours.

7.9.2. No cracking of the test piece is allowed.

7.10. Temperature cycle test

7.10.1. A non-metallic part containing hydrogen shall comply with the leakage tests mentioned in paragraphs 7.3 and 7.4 after having been submitted to a 96 hours temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under Maximum Allowable Working Pressure (MAWP).

7.11. Pressure cycle

7.11.1. Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements of paragraph 7.3, after being subjected to 6,000 pressure cycles.

7.11.2. The pressure shall change from atmospheric pressure to the Maximum Allowable Working Pressure (MAWP) of the tank within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds.

8. 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.

EN 1251-2:2000 *Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1000 litres volume — Part 2: Design, fabrication, inspection and testing*

EN 1252-1:1998/AC:1998 *Cryogenic vessels — Materials — Part 1: Toughness requirements for temperatures below –80°C*

EN 1797: 2001 *Cryogenic vessels —Gas/material compatibility*

EN 10204:1991/A1:1995 *Metallic products — Types of inspection documents*

EN 12300:1998 *Cryogenic vessels — Cleanliness for cryogenic service*

EN 12434:2000 *Cryogenic vessels — Cryogenic flexible hoses*

EN 13648-1:2002 *Cryogenic vessels — Safety devices for protection against excessive pressure — Part 1: Safety valves for cryogenic service*

EN 13648-2:2002 *Cryogenic vessels — Safety devices for protection against excessive pressure — Part 2: Bursting discs safety device for cryogenic service*

EN 13648-3:2000 *Cryogenic vessels — Safety devices for protection against excessive pressure — Part 3: Determination of required discharge — Capacity and sizing*

IEC 60529:2001 *Degrees of protection provided by enclosures (IP Code)*

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

ISO 1431-1:1989 *Rubber, vulcanized or thermoplastic — Resistance to ozone cracking — Part 1: Static strain test*

ISO 2768-1:1989 *General tolerances — Part 1 Tolerances for linear and angular dimensions without individual tolerance indications*

ISO 6957:1988 *Copper alloys — Ammonia test for stress corrosion resistance*

Alternatively applicable:
DIN 50916-2:1985 *Testing of copper alloys; stress corrosion cracking test in ammonia, testing of components*

ISO 9227:1990 Corrosion tests in artificial atmospheres — Salt spray tests

Alternatively applicable:
DIN 50021:1998 Spray tests with different sodium chloride solutions
IEC 60068-2-52:1996 *Environmental testing – Part 2: Tests — Test Kb: Salt mist, cyclic (sodium, chloride solution)*

ISO 11114-4:2004 *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test method for hydrogen compatibility with metals*

UNECE Regulation No. 94 – *Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision*

Alternatively applicable:
96/79/EC – Directive of the European Parliament and of the Council on the protection of motor vehicles in the event of a frontal impact.

UNECE Regulation No. 95 – *Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision*

Alternatively applicable:
96/27/EC – Directive of the European Parliament and of the Council on the protection of motor vehicles in the event of a side impact.

ANNEX 1: LIST OF EN/ISO EQUIVALENT STANDARDS

EN/ISO standard number	Title
EN 1251-2:2000 ISO/CD 21029-1	*Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1000 litres volume — Part 2: Design, fabrication, inspection and testing* Cryogenic vessels — Transportable vacuum insulated vessels of no more 1000 l volume — Part 1: Design, fabrication , inspection and testing
EN 1252-1:1998/AC:1998 ISO/DIS 21028-1	*Cryogenic vessels — Materials — Part 1: Toughness requirements for temperatures below –80 °C* Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperature below –80 °C
EN 1797: 2001 ISO/DIS 21010	*Cryogenic vessels —Gas/material compatibility* Cryogenic vessels — Gas/material compatibility
EN 10204:1991/A1:1995 ISO 10474:1991	*Metallic products — Types of inspection documents* Steel and steel products — Inspection documents
EN 12300:1998 ISO/WD 23208	*Cryogenic vessels — Cleanliness for cryogenic service* Cryogenic vessels — Cleanliness for cryogenic service
EN 12434:2000 ISO/WD 21012	*Cryogenic vessels — Cryogenic flexible hoses* Cryogenic vessels — Hoses
EN 13648-1:2002 ISO/WD 21013-1	Cryogenic vessels — Safety devices for protection against excessive pressure — Part 1: Safety valves for cryogenic service Cryogenic vessels — Safety accessories for cryogenic services — Part 1: Reclosable relief
EN 13648-2:2002 ISO/WD 21013-2	*Cryogenic vessels — Safety devices for protection against excessive pressure — Part 2: Bursting discs safety device for cryogenic service* Cryogenic vessels – safety accessories for cryogenic services — Part 2: Non-reclosable relief
EN 13648-3: 2000 ISO/WD 21013-3	*Cryogenic vessels — Safety devices for protection against excessive pressure — Part 3: Determination of required discharge — Capacity and sizing* Cryogenic vessels – Safety accessories for cryogenic services — Part 3: Sizing and capacity determination