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Liquid hydrogen — Land vehicle fuelling system interface

Hydrogène liquide — Interface des systèmes de remplissage 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 3.

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.

International Standard ISO 13984 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies.*

Introduction

The fuelling system interface described in this International Standard is intended to be used in conjunction with fuel tanks constructed in accordance with ISO 13985.

NOTE Pursuant to the agreement reached during the sixth plenary meeting of ISO/TC 197, the basic allowable stresses shown in Table 1 of this International Standard have been changed.

Liquid hydrogen — Land vehicle fuelling system interface

1 Scope

This International Standard specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refuelling procedure and thus to provide a reasonable level of protection from loss of life and property.

This International Standard is applicable to the design and installation of liquid hydrogen (LH_2) fuelling and dispensing systems. It describes the system intended for the dispensing of liquid hydrogen to a vehicle, including that portion of the system that handles cold gaseous hydrogen coming from the vehicle tank, that is, the system located between the land vehicle and the storage tank.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 1106-3:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness.*

ISO 1182:—[1)], *Reaction to fire tests for building products — Non-combustibility test.*

ISO 9303:1989, *Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of longitudinal imperfections.*

ISO 10286:1996, *Gas cylinders — Terminology.*

ISO 11484:1994, *Steel tubes for pressure purposes — Qualification and certification of non-destructive testing (NDT) personnel.*

ISO 12095:1994, *Seamless and welded steel tubes for pressure purposes — Liquid penetrant testing.*

ISO 13663:1995, *Welded steel tubes for pressure purposes — Ultrasonic testing of the area adjacent to the weld seam for the detection of laminar imperfections.*

ISO 13664:1997, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube ends for the detection of laminar imperfections.*

ISO 13665:1997, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube body for the detection of surface imperfections.*

[1)] To be published. (Revision of ISO 1182:1990)

ASTM A240/A240M-97a, *Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels.*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 10286 and the following apply.

3.1
design pressure
pressure used in the formula for the calculation of the minimum wall thickness for each component in the piping system

NOTE The design pressure should be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service.

3.2
fuel tank
liquid hydrogen reservoir, installed on a vehicle, with appurtenances for connecting to a refuelling station

3.3
inspector
qualified person employed by a recognized independent national or international agency

3.4
liquid hydrogen
LH_2
hydrogen that has been liquefied, i.e. brought to a liquid state

NOTE Liquefaction may be achieved by chilling and compression or other means, such as the magnetocaloric effect.

3.5
maximum permissible operating pressure
MPOP
maximum effective gauge pressure allowable in the piping system in its operating condition

3.6
noncombustible material
material that does not ignite, burn, support combustion or release flammable vapours when subjected to fire or heat in accordance with ISO 1182

3.7
operating pressure
gauge pressure at which the piping system operates

NOTE Operating pressure should not exceed the maximum permissible operating pressure.

3.8
service temperature range
temperature ranging from that of liquid hydrogen (– 253 °C) to an assumed ambient temperature of 54 °C

3.9
storage tank
liquid hydrogen reservoir, located at the refuelling station, to supply the land vehicle with liquid hydrogen

4 Requirements

4.1 Applicability

The provisions of this clause apply only to system components which handle liquid hydrogen and cold gaseous hydrogen.

4.2 Refuelling system

4.2.1 Compatibility with hydrogen and cold temperatures

All components of the refuelling system which come in contact with liquid hydrogen and cold gaseous hydrogen shall be compatible with and suitable for liquid hydrogen service and cold gas flows such as those associated with the handling of cold gaseous hydrogen returning from the vehicle fuel tank.

Consideration shall be given to the thermal expansion and contraction of piping systems when exposed to the temperature fluctuations over the service temperature range. Consideration shall be given to the possible condensation of air.

4.2.2 Material specifications

Material used in the manufacture of piping for liquid hydrogen service shall be austenitic stainless steel, or any other material provided it is proven to be equivalent in performance.

4.2.3 Piping

4.2.3.1 Design

Piping, valves, fittings, gaskets and sealants shall be suitable for hydrogen service at the temperatures and pressures involved.

Permanent joints in piping shall be made by welding or brazing; flanged, threaded or screwed joints shall not be used. Compression fittings may be used only to connect instrumentation and pressure-relief devices to the gas lines. The materials used in valves and fittings shall be suitable for liquid hydrogen service over the service temperature range. Bayonet joints shall be used for transfer operations of liquid hydrogen.

The bursting strength of all pipes, valves, fittings and hoses shall be at least four times the design pressure of the storage tank and not less than four times the pressure to which they shall be subjected in normal service by the action of a pump or other device, the action of which shall subject portions of the piping to pressures greater than the storage tank's design pressure.

Each valve shall be designed and constructed for a rated pressure and service temperature not less than those used as the design values for the storage tank or the section of piping containing the valve, whichever set of values is higher. Each valve shall be compatible with liquid hydrogen or cold hydrogen gas service.

Means shall be provided to minimize exposure of personnel to piping and to prevent air condensate from contacting piping, structural members and surfaces not suitable for oxygen enrichment or cryogenic temperatures. During an emergency when exposed to fire, heat, cold or water as applicable, insulation shall maintain any system properties that are required by design. It shall be designed to have a vapour-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation. The insulation material and outer covering shall also be of adequate design to prevent attrition of the insulation due to normal operating conditions.

4.2.3.2 Thickness requirements

The required thickness of straight sections of pipe shall be determined in accordance with equation (1):

$$t_{\mathrm{m}} = t + c \tag{1}$$

where

t_m is the nominal thickness, including mechanical, corrosion and erosion allowances, in millimetres;

t is the pressure design thickness, as calculated from equation (2), in millimetres;

c is the sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances, in millimetres.

The pressure design thickness t shall be calculated using equation (2):

$$t = \frac{PD_o}{2\,(S \cdot E + P \cdot Y)} \qquad (2)$$

where

P is the internal design gauge pressure, plus vacuum, if vacuum-insulated, in megapascals;

D_o is the outside diameter of pipe, in millimetres;

S is the basic allowable stress value for material from Table 1, in megapascals;

Y is a coefficient equal to 0,4 for austenitic steels;

E is the quality factor, which for stainless steel and seamless tubes is 1,0.

Table 1 — Basic allowable stresses (S) in tension for austenitic stainless steel tubes and pipes

Dimensions in megapascals

Designation	Specified minimum tensile strength	Specified minimum yield strength	Maximum basic allowable stress S at minimum temperature (2/3 of the yield strength)
ASTM A 240, type 304	517	207	138
ASTM A 240, type 304 L	482	172	115
ASTM A 240, type 316	517	207	138
ASTM A 240, type 316 L	482	172	115

4.2.3.3 Cyclic effects

4.2.3.3.1 Cyclic loadings

Piping and components shall be designed to accommodate the effects of metal fatigue resulting from the thermal cycling to which the system will be subjected. Particular consideration shall be given where changes in wall thickness occur between pipes, fittings, valves, components, and at areas of anchoring.

Cyclic design conditions shall include coincident pressure, temperature, imposed end-displacements and thermal expansion of the joint itself, for cycles during operation. Cycles due to transient conditions (startup, shutdown and abnormal operation) shall be stated separately.

4.2.3.3.2 Limits of calculated stress due to sustained loads and displacement strains

4.2.3.3.2.1 Internal pressure stresses

Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, including any reinforcements, meets the requirements of 4.2.3.2.

4.2.3.3.2.2 Longitudinal stresses S_L

The sum of longitudinal stresses S_L in any component in a piping system, due to pressure, weight and other sustained loadings, shall not exceed S_h in equation (4).

The thickness t of the pipe used in calculating the stress value S_L shall be the nominal thickness t_m minus mechanical corrosion and erosion allowance c [from equation (1)].

4.2.3.3.2.3 Computed displacement stress range S_E

The computed displacement stress range S_E in a piping system, given by equation (3), shall not exceed the allowable displacement stress S_A calculated by equation (4):

$$S_E = \sqrt{S_b^2 + 4\,S_t^2} \tag{3}$$

where

S_b is the resultant bending stress, in megapascals;

S_t is the torsional stress, in megapascals.

4.2.3.3.2.4 Allowable displacement stress range S_A

$$S_A = f(1{,}25\,S_c + 0{,}25\,S_h) \tag{4}$$

where

S_A is the allowable displacement stress, in megapascals;

S_c is the basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis, in megapascals;

S_h is the basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis, in megapascals.

When S_h is greater than S_L, the difference between them may be added to the term 0,25 S_h in equation (4). In this case, the allowable displacement stress is calculated by equation (5):

$$S_A = f[1{,}25\,(S_c + S_h) - S_L] \tag{5}$$

where

S_L is the sum of longitudinal stresses in any component in the piping system due to pressure, weight and other sustained loadings, in megapascals;

f is the stress range reduction factor from Table 2 or calculated by equation (6):

$$f = 6{,}0[N]^{-0{,}2} \leqslant 1 \tag{6}$$

where

N is the equivalent number of full displacement cycles during the expected service life of the piping system;

S_b is the resultant bending stress, in megapascals;

S_t is the torsional stress, in megapascals.

Table 2 — Stress-range reduction factor *f*

Cycle N	Factor f
7 000 or less	1,0
over 7 000 to 14 000	0,9
over 14 000 to 22 000	0,8
over 22 000 to 45 000	0,7
over 45 000 to 100 000	0,6
over 100 000 to 200 000	0,5
over 200 000 to 700 000	0,4
over 700 000 to 2 000 000	0,3

When the computed stress range varies, whether from thermal expansion or other conditions, S_E is defined as the greatest computed displacement stress range. The value of N in such cases can be calculated by equation (7):

$$N = N_E + \sum (r_i^5 N_i) \quad \text{for } i = 1, 2, \dots n \qquad (7)$$

where

N is the number of cycles of maximum computed displacement stress range, S_E;

r_i is the ratio of S_i to S_E (S_i / S_E);

S_i is any computed displacement stress range smaller than S_E;

N_i is the number of cycles associated with displacement stress range S_i.

4.2.3.4 Fixed piping

Exterior piping shall be installed above-ground and shall be well supported and protected against mechanical damage. Piping shall be protected from corrosion in compliance with present recognized practices.

The refuelling system piping shall be suitably supported and anchored, and insulated for the liquid hydrogen service at the design pressure.

Manifolds connecting the storage tank shall be fabricated to minimize vibration and shall be installed in protected locations or shielded to prevent damage from unsecured objects.

Piping and fittings shall be clear and free from cutting burrs and scales, and the ends of all piping shall be reamed.

Any piping fabrication process shall not reduce its pressure rating below the design pressure.

A joint or connection shall be located in an accessible location.

Hydrogen shall only be vented to a safe point of discharge. A vent pipe shall be connected to a point at the top of the storage tank to prevent any trace of hydrogen remaining, and shall have the open end suitably protected to prevent entrance of rain, snow and solid material. Vertical vent pipes shall have provision for drainage.

4.2.3.5 Pipe supports

Pipe supports, including pipe-supporting insulation systems, shall be resistant to or protected against exposure to fire or escaping cold liquid hydrogen, or both, if they are subject to such exposure.

4.2.4 Refuelling hoses

Design of the refuelling hoses shall be met according to the state of the art and manufacturer's experience.

The refuelling hoses shall consist of vacuum or otherwise suitably insulated flexible hoses for the hydrogen to remain in its liquid form. The hoses shall be suitably equipped for the ventilation of any gaseous hydrogen that may form.

The insulation shall maintain any properties that are required by design during an emergency when exposed to fire, heat, cold or water as applicable.

Whenever a loss of vacuum is detected, or if condensation or frost appears on the external surface of the hose during use, the hose shall be taken out of service until the vacuum has been restored.

Each coupling used on a hose to make connections shall be appropriately designed so that there will be no leakage where it is connected.

Gasket materials suitable for service with liquid hydrogen and that are properly sized shall be used for this service. Loose-fibre gasket material that can be readily fretted shall not be used, since the loose particles may contaminate the system. O-rings and O-ring grooves shall be matched properly for the design service conditions of low temperature and hydrogen exposure.

The maximum permissible operating pressure of the transfer equipment shall be rated equal to or greater than the storage tank design pressure or the discharge pressure of pumps or other devices, whichever is higher. Where dual hoses are used, provisions shall be made for gas recovery or venting.

Sharp bends and twists shall be avoided in the routing of flexible hose. A minimum of five times the outside diameter of the hose is considered acceptable as a bend radius.

The use of hose in an installation shall be limited to:

a) a vehicle fuelling hose;

b) an inlet connection to compression equipment;

c) a section of metallic hose not exceeding 1 m in length to provide flexibility where necessary. Each section shall be installed so that it will be protected against mechanical damage and be readily visible for external inspection. The manufacturer's identification shall be retained in each section.

4.2.5 Pressure-relief devices

The design, material and location of pressure-relief devices shall be suitable for the intended service.

When fittings and piping are used on the upstream and/or downstream sides of pressure-relief systems, the passages shall be designed so that the flow capacity of the pressure relief systems will not be reduced below the capacity required for the storage tank on which the pressure-relief systems are installed. The opening through all piping and fittings shall have at least the same flow area as the inlet of the pressure-relief device to which it is connected. The nominal size of the discharge piping shall be at least as large as that of the pressure-relief device outlet. Oversized pressure-relief devices may be used without requiring all openings in their lines to have the same flow area, provided the required flow capacity is assured through the system.

Each pressure-relief device shall be subjected to an air or gas pressure test to determine:

a) that the start-to-discharge pressure setting is within tolerances of the set pressure marked on the valve as required by an applicable standard;

   CAUTION: In setting the valve, care shall be taken that evidence of start-to-discharge is due to opening of the valve and not due to a defect.

b) that after the start-to-discharge pressure test, the resealing pressure is not less than 90 % of the start-to-discharge pressure. If the valve has adjustable blowdown, the resealing pressure shall not be less that 95 % of the start-to-discharge pressure.

Pressure-relief devices shall be so arranged that the possibility of damage to piping or appurtenances is reduced to a minimum. The means for adjusting pressure-relief-valve set pressure shall be sealed.

The discharge piping from pressure-relief devices shall be properly supported to withstand the reaction forces generated during maximum rate of discharge.

Pressure relief valves shall be inspected and set point tested at least once every 30 months, with intervals not exceeding 30 months, to ensure that each valve relieves at the proper setting.

A pressure-relief device shall be provided in the transfer system to prevent overpressure.

A pressure-relief valve shall be installed as required to prevent overpressure caused by thermal expansion in any section of a liquid or cold-vapour pipeline that can be isolated by valves.

These pressure-relief valves shall be set to discharge at or below the design pressure of the section of the piping or hose they protect.

Discharge from such pressure-relief valves shall be directed to minimize hazard to personnel and equipment.

4.2.6 Vehicle refuelling connections

A vehicle refuelling connection shall provide for the reliable and secure connection of the fuel tanks to a source of liquid hydrogen only.

The transfer connections shall be keyed, sized or located so that they cannot be cross-connected, thereby minimizing the possibility of connecting incompatible gaseous fluids or pressure levels. The connectors and fittings to be disconnected during operations shall be provided with tethered end plates, caps, plugs or covers to protect the system from contamination or damage when not in use. Pressure relief shall also be provided if cold fluid can remain trapped in the lines. The fuelling connection shall prevent escape of hydrogen, in either its gaseous or liquefied form, when the connector is not properly engaged or becomes separated.

The end of the liquid-hydrogen fuelling hose shall be equipped with a suitable male vacuum-jacketed coupling capable of connecting to a vacuum-jacketed female coupling on the vehicle.

Purging shall also be possible with the connector coupling mechanism or when coupled.

The dispensing device shall be protected from vehicle collision damage.

An emergency shutdown system (ESD) shall be provided that includes a shutoff valve for stopping liquid supply and shutting down transfer equipment. An actuator, distinctly marked for easy recognition with a permanently affixed, legible sign, shall be provided near the dispenser and also at a safe, remote location.

Hoses and arms shall be equipped with a shutoff valve at the free end and with devices to minimize release of liquid and vapour in the event that a vehicle pulls away while the hoses remain connected.

A means shall be provided to supply the fuelling system operator with the level and pressure of liquid hydrogen in the fuel tank to prevent from overfilling and overpressurising. The level and pressure devices shall be calibrated on a periodic basis.

The fuelling connector either shall be equipped with an interlock device that prevents release while the line is open or shall have self-closing ends that automatically close upon disconnection.

When not in use, hoses shall be secured and the fuelling connector provided with a storage bracket to protect it from damage.

The fuelling connector shall be suspended by a tethering device that prevents it from coming in contact with the ground at any position between its storage bracket and the vehicle female coupling.

A grounding connector and cable shall be provided from the refuelling station to a ground connector on the vehicle being refuelled. Any tools used in the refuelling operation shall be non-sparking.

4.3 Installation of piping and hoses

4.3.1 Layout

Piping and hoses shall be run as directly as practical.

4.3.2 Welding

Qualified welding procedures shall be selected to minimize degradation of the low temperature properties of the pipe material. Welds shall be inspected using radiographic or ultrasonic testing or other equivalent non-destructive testing as described in clause 5.

4.4 Equipment assembly

Piping, valves, regulating equipment and other accessories shall be readily accessible and shall be protected against physical damage and against tampering.

A remotely controlled shutoff valve shall be located in the liquid-hydrogen withdrawal piping as close to the storage tank as practical. No connection, flange or other appurtenance except a welded manual shutoff valve shall be installed in the piping between the remotely controlled shutoff valve and its connection to the storage tank.

An emergency device shall be provided whereby the operator of the refuelling interface can readily activate the shutoff valve during refuelling.

After installation, all field-erected piping shall be tested and proved hydrogen gas-tight according to the leak testing procedure described in 5.6.

Any material present underneath the transfer hoses shall be noncombustible.

4.5 Transfer method

4.5.1 Cleanliness and purges

All transfer hoses in liquid hydrogen service shall be purged with helium or hydrogen gas to remove other gases and contaminants before insertion of liquid hydrogen into the line. Purges subsequent to hydrogen use, for shutdown or maintenance purposes, shall be made with an inert gas such as helium.

If the fuelling system can be maintained by any means under continuous hydrogen pressure, purging need not be performed.

4.5.2 Electrical grounding and bonding

All conductive sections in the fuelling system interface shall be bonded to the rest of the system or grounded. Electrically isolated conductive sections shall not be used. Sufficient grounding connections shall be provided to prevent any measurable static electricity charge from accumulating on any component.

The bonding connections shall be made before the final installation of the transfer system.

The resistance to ground shall be less than 10 Ω.

5 Testing and inspection methods

5.1 Examination requirements

Prior to initial operation, each piping installation, including components and workmanship, shall be examined as described in 5.3.1, 5.3.2, 5.3.3 and 5.3.4. Joints not included in these examinations, or those for which the manufacturer is not requiring examination, are accepted if they pass the leak test of 5.6.

5.2 Acceptance criteria

Acceptance criteria shall be as guaranteed by the manufacturer.

5.3 Examination types

5.3.1 Extent of examination

Piping shall be examined to the extent specified in this International Standard or to any greater extent specified by the manufacturer.

5.3.2 Visual examination

All the fabrication shall be visually inspected to ensure that it conforms to specifications and is free from defects. The assemblies of all threaded, bolted and other joints shall be examined.

All piping erection shall be examined to verify dimensions and alignment. Supports, guides and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation and shutdown will be accommodated without binding or constraint.

5.3.3 Other examination

Not less than 5 % of circumferential butt and mitre groove welds shall be examined fully by random radiography in accordance with 5.4.2 or by random ultrasonic examination in accordance with 5.4.3. Socket welds and branch connection welds which are not radiographed shall be examined by magnetic particle or liquid penetrant methods in accordance with 5.4.4.

5.3.4 In-process examinations

In-process examination, supplemented by appropriate nondestructive examination, may be substituted for the examination required in 5.3.2 on a weld-to-weld basis if specified by the manufacturer or specifically authorized by the Inspector.

5.3.5 Certification and records

Certifications, records and other evidence that the materials and components are of the specified grades and that they have received required heat treatment, examination, and testing shall be retained by the manufacturer.

5.4 Examination procedures

5.4.1 Qualification of personnel and written procedures

Required examination shall be performed in accordance with a written procedure that conforms to one of the methods specified in the following subclauses of this International Standard. The personnel performing the testing shall be qualified and certified in accordance with ISO 11484.

5.4.2 Radiographic examination

Radiography of welds and of components other than castings shall be performed in accordance with ISO 1106-3.

5.4.3 Ultrasonic examination

Ultrasonic examination of welds and of the area adjacent to the weld seam shall be performed in accordance with ISO 9303 and ISO 13663.

5.4.4 Magnetic particle and liquid penetrant examination

Magnetic particle examination of welds shall be performed in accordance with ISO 13664 and ISO 13665.

Liquid penetrant examination of welds shall be performed in accordance with ISO 12095.