GASEOUS HYDROGEN STATIONS

AIGA 045/07

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Acknowledgement

This document is adapted from the European Industrial Gases Association IGC 15/05 E 'Gaseous hydrogen stations'. Acknowledgement and thanks are hereby given to EIGA for permission granted for the use of their document.

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1 Introduction

This document has been prepared for the guidance of designers and operators of gaseous hydrogen stations. It is considered that it reflects the best practices currently available. Its application will achieve the primary objective of improving the safety of gaseous hydrogen station operation.

2 Scope

The Code covers gaseous hydrogen, compression, purification, transfilling and storage installations at consumer and manufacturing sites. It does not include production, transport or distribution of hydrogen, nor does it cover any safety aspects in the use and application of the gas in technical or chemical processes.

3 Properties of hydrogen

Hydrogen is the lightest gas known (specific gravity 0.0695; air = 1) and diffuses rapidly in air.

Hydrogen is colourless, odourless and tasteless.

Hydrogen is non-toxic, does not support life and may act as an asphyxiant by replacing the oxygen content in a confined space.

Hydrogen is extremely flammable in air (flammability limits 4 % to 75 % by volume). The energy required to ignite it is extremely small e.g. static electricity and under certain conditions spontaneous ignition may occur.

Hydrogen burns in air with a very hot and almost invisible flame, which emits very little radiant heat and therefore gives limited warning of its presence.

Hydrogen can diffuse rapidly through materials and systems, which are leak-tight with air or other common gases. Diffusion is more pronounced at elevated temperatures.

4 General design features

4.1 Design

Hydrogen systems shall be designed, fabricated and tested in accordance with recognised national pressure vessel and piping codes.

Pressure relief devices shall be provided to prevent over pressure where this can occur. Relief devices and vents are to be routed away to a safe location.

Equipment and systems shall be earthed and bonded to give protection against the hazards of stray electrical currents and static electricity.

4.2 Location

Hydrogen systems may be installed outdoors or within suitably designed buildings with adequate accessibility for fire fighting and other emergency services. Consideration should also be given to provide adequate means of escape for personnel in the event of an emergency.
Systems shall not be located beneath high voltage power lines.

Care shall be exercised with regard to their location relative to sources of fuel, such as pipelines or bulk storage containing other flammable gases or liquids, or other potential hazardous substances which could jeopardise the integrity of the installation.

Safety distances -see Table 1.

Consideration shall be given to the proximity of other processes or buildings containing process equipment, where there is a potential fire or explosion hazard. Adequate precautions, such as increased separation distances or adding properly designed fire protection walls may be necessary in such cases.

Systems shall be adequately protected from damage caused by vehicular traffic and from tampering by unauthorized personnel...

4.3 Buildings

4.3.1 Design and buildings

Buildings in which hydrogen systems are installed shall be of single storey construction, be designed for the purpose and be well ventilated especially at high points.

The degree of enclosure should be the minimum consistent with providing a reasonable working environment in relation to local weather conditions.

Adequate measures shall be taken to ensure that hydrogen cannot penetrate into service ducts, electrical conduits, staircases and passages that connect to locations that are designated as safe areas, i.e. outside the hazard zone (see 5).

Buildings and doorway shall be of fire resistant construction as determined by national codes or regulations. Provision of means of escape shall comply with 11.

Explosion relief blowout panels shall be provided in exterior walls or roofs and should be designed so that if an explosion occurs the pressure will be relieved safely.

The total relieving area should not be less than either the area of the roof or the area of one of the longest sides. This area may consist of any one or a combination of the following

- Area open to the outside
- Walls of light non-combustible material
- Outward swing doors in exterior walls
- Lightly fastened hatch covers
- Light roof design

Lighting and other electrical components must be designed for the environment and to meet national electrical codes.

4.3.2 Heating

Where heating is required, it should preferably be by hot water or warm air. Where re-circulatory systems are used, consideration shall be given to the possibility of hydrogen contamination and adequate precautions shall be taken. The heat sources shall be located remote from the buildings and comply with the distances specified out in Table 1, page 5. Where an electrical source for heating is used, it shall comply with the requirement for electrical equipment outlined in 10.

4.3.3 Ventilation

The building shall have good low and high-level natural ventilation to the open air. Outlet opening shall be located at the highest point of the room in exterior walls or roof.

In areas where natural ventilation is not possible, consideration shall be given for the installation of permanent atmosphere analysis equipment with suitably located point (s), and /or forced air ventilation.

4.4 Pipelines and Discharge Devices

Pipelines for hydrogen shall be clearly marked by means of colour coding and/or labels.

Isolation valves shall be provided so that the hydrogen source can be shut off safely in the event of an emergency. This is particularly important where hydrogen pipelines enter buildings.

The vents of pressure relief devices shall be designed or located so that moisture cannot collect and freeze in a manner, which could interfere with the proper operation of the device. Copper alloys or stainless steel are preferred materials to minimise the possibility of ignition due to atmospheric corrosion particles.

Vents, including those of pressure relief devices, shall be arranged to discharge in a safe place in the open air so as to prevent impingement of escaping gas on to personnel or any structure. Vents should be piped individually, manifolding is not recommended. Vents shall not discharge where accumulation of hydrogen can occur, such as below the eaves of buildings.

Where it is necessary to run hydrogen pipelines in the same duct or trench used for electrical cables, then all joints in the hydrogen pipelines in the ducted/trenched section shall be welded or brazed. A minimum separation distance of 50 mm from electrical cables and any other pipelines shall be maintained. The hydrogen pipeline should be run at a higher elevation than other pipelines.

4.5 Materials

All materials used shall be suitable for hydrogen service and for the pressures and temperatures involved.

Cast iron pipe and fittings shall not be used. The use of any casting is not recommended due to the permeability of hydrogen and the possibility of porosity in the casting.

Pipes and fittings shall conform to an established standard or specification for their manufacture.

Under certain conditions, some high tensile ferrous materials are susceptible to hydrogen embrittlement. Due considerations shall be given when selecting ferrous materials for hydrogen service.

Where ammonia is likely to be present as an impurity, or as an atmospheric contaminant, copper and copper/tin/zinc base alloys shall not be used for pipe or fittings since these materials are susceptible to attack by ammonia. Consideration should also be given to the possibility of other contaminants being present and adequate precautions be taken.

4.6 Connections

Joints in piping and tubing should be made by welding, brazing (soft solder is not recommended) flanged or threaded fittings.

The use of compression fittings, ferrous or nonferrous, is not recommended. Where it is considered that compression fittings are necessary in the design of the system (such as small bore instrument lines and valves) then strict observance of the manufacturers' instructions for use and fitting shall be followed; including compliance with manufacturers’ torquing procedures.

The use of welded or brazed joints is recommended wherever possible. Where breakable joints (threaded, flanged etc.) are considered necessary, these should be kept to a minimum since they are a potential source of leakage. Particular care shall be taken in the use of such connections due to the permeability of hydrogen at all pressures.

Electrical continuity shall be maintained throughout the system (see 10.3).

The free end of filling hose connections, where threaded, shall have a left hand thread that complies with recognized standards. Filling hoses shall be electrically continuous. The material of construction shall provide the best possible resistance to permeation. Where outer sleeves are fitted, these shall be suitably pierced to prevent accumulation of hydrogen due to leakage. Each hose shall have been hydraulically tested by the manufacturer and a certificate issued to that effect... Safety devices should be considered to restrain hoses in the event of failure.

4.7 Instruments

Instruments and gauges shall be designed and located such that, in the event of a leakage or rupture, and possible subsequent fire, the risk to personnel is minimised. The use of safety glass and blow-out backs on pressure gauges is recommended.

Certain instruments may use detection systems, which are not normally compatible with hydrogen safety precautions, e.g. gas chromatographs, flame ionisation detectors. In these instances adequate precautions shall be taken to limit quantities of hydrogen, within analysis instruments, to acceptable limits, e.g. by inert gas purging and venting to the outside.

5 Hazard zones

5.1 Minimum recommended safety distances

Hydrogen systems shall be surrounded by hazard zones. The extent of these zones is given in Table 1. The distances are measured from those points in plan view at which, in the course of operation, an escape of hydrogen may occur. Where equipment is installed within buildings, the distances to outside types of exposure are measured from the openings, e.g. windows, doors etc.

Pipelines that contain valves, flanges, removable connections etc. shall be considered as sources of hydrogen escape only at the points where such connections occur.

The distances given in Table 1 may be reduced by the provision of suitable fire resistant barrier walls. The type and dimensions of the barrier and the distance reduction achieved will be determined by the conditions at the source of hydrogen and the nature of the exposure.

Activities other that those directly related to the hydrogen operation should be kept remote from hydrogen equipment.

The distances given in Table 1 are the minimum recommended. Where National Codes or Regulations specify greater distances, these shall apply.

All electrical equipment within a building, where there is a possible source of hydrogen escape, and within the distance specified in Table 1, shall be of an approved type in accordance with existing; National Electrical Codes of Practice or Regulations. Such approved equipment shall not be considered as a source of ignition.

Table 1 – Minimum safety distances

Type of outdoor exposure		Total gaseous hydrogen storage		
		Less than 99m³ (3500 scf)	**99m3 to 425m³** (3500 to 15000 scf)	**In excess of 425m³** (15000 scf)
		metres	**metres**	**metres**
1.	Building or structure			
	(a) Wall(s) adjacent to system constructed of noncombustible or limited combustible materials			
	(1) Sprinklered building or structure or unsprinklered building or structure having noncombustible contents	0	1.5a	1.5 a
	(2) Unsprinklered building or structure with combustible contents. Adjacent wall(s) with fire resistance rating less than 2 hours[b]	0	3	8
	Adjacent wall(s) with fire resistance rating of 2 hours or greater[b]	0	1.5	1.5
	(b) Wall(s) adjacent to system constructed of other than noncombustible or limited-combustible materials	3	8d	8d
2.	Wall openings			
	(a) Not above any part of a system	3	5	5
	(b) Above any part of a system	8	8	8
3.	All classes of flammable and combustible liquids above ground			
	(a) 0 - 3785 L (1000 gal)	3	8	8
	(b) In excess of 3785L (1000 gal)	8	8	8
4.	All classes of flammable and combustible liquids below ground — 0 - 3785L (1000 gal)[e]			
	(a) Tank	3	3	3
	(b) Vent or fill opening of tank	5	5	5
5.	All classes of flammable and combustible liquids below ground — in excess of 3785L (1000 gal)[e]			
	(a) Tank	3	3	3
	(b) Vent or fill opening of tank	5	5	5
6.	Flammable gas storage (other than hydrogen), either high pressure or low pressure			
	(a) 0 - 425 m^3 (15,000 scf) capacity	3	8	8
	(b) In excess of 425 m^3 (15,000 scf) capacity	8	8	8
7	Oxygen storage	8	8	8
8.	Fast-burning solids such as ordinary lumber, excelsior, or paper	8	8	8
9.	Slow-burning solids such as heavy timber or coal	8	8	8
10.	Open flames and welding	8	8	8
11.	Air compressor intakes or inlets to ventilating or air-conditioning equipment	15	15	15
12.	Places of public assembly	8	15	15
13.	Public sidewalks and parked vehicles	5	5	5
14.	Line of adjoining property that can be built upon	1.5	1.5	8

a Portions of wall less than 3m (10 ft) (measured horizontally) from any part of a system shall have a fire resistance rating of at least 1 hour.

b Exclusive of windows and doors (*see number 2 of Table 1*).

c Portions of walls less than 3m (10 ft) (measured horizontally) from any part of a system shall have a fire resistance rating of at least 1 hour.

d But not less than one-half the height of adjacent wall of building or structure.

e Distances can be reduced to 4.5m (15 ft) for Class IIIB combustible liquids.

5.2 Identification of and Access to Hazard Zones

The extent of the hazard zones shall be indicated by permanent notices, particularly at access points, or by distinctive lines painted on the ground. Notices shall indicate the nature of the hazard, e.g.

HYDROGEN - FLAMMABLE GAS
NO SMOKING - NO OPEN FLAME

Only authorised personnel shall be allowed to enter these zones. These personnel shall be aware of the hazards likely to be encountered and the relevant emergency procedures.

Any work other than that directly connected with operating the station shall be covered by a Safety Work Permit system.

6 Compression

6.1 Definition

A hydrogen compressor is a machine, which raises the pressure of incoming hydrogen to a higher value.

All types of compressors are acceptable provided that they have been designed with particular reference to hydrogen service.

Special attention shall be given to prevent the ingress of air.

6.2 Flowsheet Description

Appendix 1 shows a flowsheet of a typical hydrogen compressing system using a multistage piston machine.

Hydrogen enters the compressing system through the inlet isolation valve (1). A purge valve (2) fitted with a sealing device (3) shall be provided to allow the system to be purged with nitrogen. A filter (4) should be provided. A pressure indicator/alarm low (5) shall be provided on the suction line. An oxygen analyser (6) may be provided, (see 6.4.2).

At the outlet of each stage of the compressor (7) a pressure indicator (8) and a temperature indicator (9) should be fitted. Temperature indicators (*) (9) may also be fitted after each cooler (10/13).

* The inclusion of these items will be dependent on the condition of the incoming hydrogen and the requirements for the compressed product.

Full flow relief valves (11) shall be installed after each stage. Drain/vent valves (*) (12) may also be provided after each cooler.

The following items may be provided after the final stage:

- After-cooler (*) (13)
- Temperature alarm high (14)
- Separator and drain (*) (15)

* The inclusion of these items will be dependent on the condition of the incoming hydrogen and the requirements for the compressed product.

A pressure indicator/alarm high (16), a non-return valve (17), a vent/purge valve (18), and an outlet isolation valve (19) shall be installed.

Cooling water systems shall be provided with a pressure alarm low (20) or a flow alarm low (21) located at the inlet or outlet of the compressor cooling system. Additionally visual flow indicators may be provided.

Where closed circuit water-cooling is used, each cooler should be protected against over-pressure on the water side, arising from leakage of failure of the gas side.

If the electric motor (22) is pressurised or purged with nitrogen, it shall be equipped with a low pressure or flow alarm If the compressor crank case is pressurised with hydrogen or inert gas, a pressure relief device shall be fitted.

6.3 Operating Instructions

When starting a hydrogen compressor it is important to prevent ingress of air, which could lead to the formation of explosive mixtures within the machine.

It is essential therefore that the particular safety devices mentioned in 6.4 shall be operational. With these conditions satisfied, hydrogen compressors may be started up as any other compressor in accordance with the manufacturer's instructions and the following recommended start-up procedures.

6.3.1 Start-up of new compressors or compressors following Maintenance Work

Isolate the compressor by closing main isolation valves (1 and 19). Purge air from the compressor by removing sealing device (3) and connect a source of nitrogen to this point. Open purge valve (2) to pressurise the machine with nitrogen. Pressure used will depend on normal duty of machine, usually not less than half design inlet value is recommended, particularly for low suction pressure machines.

Open vent/purge valve (18) and set an adequate purge nitrogen flow.

Check that the safety devices under 6.4 are operational.

Start the compressor and leave running for approx. ten minutes.

Where possible check the oxygen content of the gas discharging from the purge/vent valve (18); when this is less than 1 % for a minimum period of two minutes shut down the compressor.

Close purge inlet valve (2) and purge/vent valve (18), disconnect the nitrogen supply and refit blanking device (3). The compressor is now ready for start-up in hydrogen service. This should be done as follows

- Open main isolation valve (1). Check that the safety devices under 6.4 are operational.
- Start the compressor.
- Open purge/vent valve (19) and analyse vent gas
- When analysis is satisfactory, i.e. nitrogen content is reduced to an acceptable value.
- Close purge/vent valve (18)
- Open outlet isolation valve (19) to put machine into service.

6.3.2 Restarting of compressors already in hydrogen service

Check that the safety devices under 6.4 are operational.

Start the compressor.

6.3.3 Shutdown of compressors

Stop the compressor.

If the compressor is to remain in hydrogen service it may be either, left standing connected to the system or, isolated by closing main isolation valves (1 and 19). Residual pressure may be vented down via purge/vent valve (18). Care shall be exercised that, during periods of shutdown, a positive residual hydrogen pressure is maintained within the machine, otherwise on restart the purging procedure detailed in 6.3.1 shall be followed.

6.4 Control and Monitoring Equipment

In addition to the instruments and controls normally provided for gas compressing systems, the following specific safeguards for hydrogen shall be considered.

6.4.1 Inlet Pressure

The inlet pressure shall be monitored by a pressure indicator/switch to avoid a vacuum in the inlet line and consequent ingress of air. This pressure switch shall cause the compressor to shut down before the inlet pressure reaches atmospheric pressure.

6.4.2 Oxygen analysis

Where the hydrogen comes from a low-pressure source, or there is a possibility of oxygen contamination, the oxygen content in the hydrogen shall be continuously measured. Should the oxygen content reach a level of 1 %, then the compressor shall be automatically shut down.

The location of the oxygen analyser may be either immediately before the suction inlet to the compressor, which is preferred, or after the first stage discharge if the suction inlet pressure is not sufficient for the analyser.

6.4.3 Discharge temperature

The temperature after the final stage, or after cooler, where fitted, shall be monitored by an indicator/alarm, which may be arranged to shut down the compressor at a predetermined maximum temperature.

6.4.4 Discharge Pressure

The pressure after the final stage shall be monitored by an indicator/alarm, which may be arranged, either to shut down the compressor, or initiate alternative actions e.g. recycle at a pre-determined maximum pressure, which is below that of the final relief device.

6.4.5 Cooling water

A water pressure/flow alarm shall be provided in the cooling water system, which may be arranged to shut down the compressor in case of low pressure or flow.

6.4.6 Purge gas on electrical equipment

Where the motor and auxiliary equipment are pressurised by an inert gas, e.g. nitrogen, low pressure/flow shall be indicated by an alarm. This may be arranged to shut down the motor and auxiliaries.

6.4.7 Pressurised crank cases

Where the compressor crankcase is pressurised by hydrogen or inert gas, low pressure/ flow shall be indicated by an alarm. This may be arranged to shut down the compressor.

7 Purification

7.1 Definition

The purification system consists of equipment to remove oxygen, moisture and other impurities from the hydrogen.

The system may comprise purification vessels, driers, heat exchangers, control and analytical equipment.

7.2 Flowsheet description

Appendix 2 shows a flowsheet of a typical hydrogen purification system.

Impure hydrogen enters the system through the inlet isolation valve (1). A separator (2) removes free droplets of moisture and oil. Removal of vapour phase contaminants, e.g. ammonia or mercury is achieved in an activated charcoal filter (3). A dust filter (4) prevents adsorbent dust carry-over.

Where necessary a pre-heater (5) is fitted to heat the gas stream before entry into the Deoxo catalyser (6). The catalyst temperature is indicated (7). An after cooler (8) and separator (9) reduces the water content in the gas stream before it passes to the adsorption driers (10). The pressure (11) and temperature (12) are indicated. A dust filter (13) removes any carryover of adsorbent dust. The analytical system (14) normally monitors oxygen and moisture content. Additional analytical equipment may be installed according to the specification required.

Product gas leaves the system via an outlet isolation valve (15).

The driers are reactivated by a suitable system.

7.3 Operation

7.3.1 Operating instructions

Detailed operating instructions shall be prepared for each purification system making individual reference to the valves and controls in that system.

7.3.2 Separator and filters

The main aspects of operation with these items are to ensure that separator drains are operated as frequently as necessary to avoid carry-over of free droplets of contaminants.

It is essential that only vapour phase contaminants reach the activated charcoal filter, otherwise rapid breakthrough will occur with subsequent reduction in efficiency of the Deoxo catalyst. This may also happen if charcoal dust carries over.

7.3.3 Deoxo catalyser

The Deoxo catalyser removes the oxygen present in the feed gas by combining it with some of the feed hydrogen to produce water. The reaction is promoted by a metal based catalyst, e.g. platinum, and is exothermic.

The operating temperature of the reaction is dependent on the quantity of oxygen present in the feed gas. Under certain conditions, e.g. low gas temperature, or excess moisture, it may be necessary to pre-heat the gas to aid the reaction. The process is normally highly efficient and residual levels of oxygen of less than 1 vpm are achieved. Although the maximum allowable oxygen content into a Deoxo unit is 3 %; in the case of hydrogen, because of the proximity to the flammability limit a maximum oxygen content of 1 % is recommended. High oxygen content will result in high temperature on catalyst and vessel construction materials.

Temperature indication of the catalyst bed is recommended.

The catalyst is very durable and provided there are no contaminants present, e.g. in the form of oil: mercury, charcoal, etc., it will have a life of several years.

The after cooler and separator reduce the gas temperature and water content of the hydrogen to acceptable levels for the driers. Attention shall therefore be given to cooling water flows and frequency of separator drainage.

7.3.4 Driers

The driers contain an adsorbent desiccant in granular form. The desiccant retains the moisture, but before its capacity is reached, it has to be reactivated by thermal or pressure swing methods.

The thermal method requires a volume of, either dry hydrogen, or an inert gas to be heated and passed through the wet bed until the retained moisture is driven off from the desiccant. Other methods, such as direct heating of the desiccant, may also be employed. Finally the desiccant is cooled before the vessel is returned to drying duty.

In the pressure swing method, moisture is adsorbed by the desiccant at relatively high pressure and released at a lower pressure.

The main points of operation of both systems are to ensure that the bed is not overloaded with moisture and design cycle times are maintained.

Particular attention shall be paid in order to avoid over pressure in the reactivation system. This can achieved by relief devices or other design features.

7.4 Control and monitoring equipment

7.4.1 Deoxo catalyser temperature indicator

An increase in oxygen content will result in temperature rise on account of the increased exothermic reaction; therefore the temperature should be monitored by an indicating instrument This instrument may be connected to an alarm and/or a shut down system.

If the indicating instrument is not of the recording type the temperature should be logged at regular intervals.

7.4.2 Temperature indicator

Monitoring of the gas temperature down stream of the driers will give an indication, whether the drier has been cooled correctly after reactivation.

7.4.3 Pressure indicator

These instruments indicate the vessel pressure during operation, they can also be used to ensure that the off stream vessel has been correctly depressurised before reactivation.

7.4.4 Purity analysers

The product quality should be checked by means of appropriate analytical instruments to ensure the correct operation of the purification system.

8 Filling stations

8.1 Definitions

A hydrogen filling station is any installation where gaseous hydrogen is transferred, under pressure from a compression system and/or bulk hydrogen storage into single cylinders, cylinders manifolded into bundles, or cylinders which form a fixed load on a road or rail vehicle.

The filling station may comprise fixed storage containers, inter-connecting pipework, filling manifolds, hoses, valves, control system, analysis equipment and vacuum pumps.

8.2 Flowsheet Description

Appendix 3 shows a flowsheet of a typical hydrogen filling station.

8.2.1 Main feeder system

Hydrogen from the compressor/purifier system enters the main header of the filling system.

It passes through a non-return valve (1) and a main isolation valve (2).

A remote operated shut-off valve (3) may be provided so that, in the event of a hazardous occurrence at the filling point, the hydrogen flow may be shut off from the local emergency stops (4). Alternatively, the remote stops may be arranged to shut down the compressors.

An oxygen analyser (5) may be fitted in the main header, if analysis is not provided on the compressor/purification system.

The header can then be sub-divided to feed the various types of filling activities. Each branch should be provided with an isolation valve (6).

8.2.2 Cylinder filling

A pressure indicator (7) shall be provided on the main feeder to the cylinder filling area. A pressure alarm high (8) or a pressure recorder may also be added. A non-return valve (9) should be provided so as to ensure, in the event of a rupture at one of the other filling areas, that back-flow does not occur.

Each individual filling manifold shall be provided with an isolation valve (10), a vent/ purge outlet valve (11) and a pressure indicator (12). A vacuum system isolation valve (13) shall also be provided where a vacuum system is used. Individual fill point isolation valves (14) may also be provided.

The vacuum system, where used, may be permanently piped in or may exist as a mobile unit. It shall be provided with adequate relief device(s) (15) to protect the system from the charging pressure of the cylinder filling manifold. Means should also be provided to exclude any backfeed of oil from the vacuum pump into the manifold. Vacuum gauges (16) should be provided.

8.2.3 Bundles trailers and railcar filling

A pressure indicator (17) shall be provided on the main feeder to the filling area. A pressure alarm high (18) or a pressure recorder may also be added.

A non-return valve (19) should be provided so as to ensure that, in the event of a rupture at any of the filling areas, back flow does not occur from the containers being filled.

Each individual filling manifold shall be provided with an isolation valve (20), a vent/ purge outlet valve (21) and a pressure indicator (22), if one is not provided on the individual units.

A non-return valve (23) should be provided in the hose connection to prevent back flow from the unit in the event of a hose rupture.

A safe means of depressurising/purging the pipe section between the non-return valve (23) and the isolation valve (24) shall be provided. This can be achieved with a small bore vent valve installed between the non-return valve (23) and the isolation valve (24) or by drilling a small hole (1,5 mm maximum diameter) in the plug/flap of the non-return valve (23).

This last method would also allow analysis samples to be taken from the unit being filled direct to any analysis instruments connected to the system.

If a vacuum system is required, it shall comply with the requirements stated in 8.2.2.

Care should be exercised to ensure satisfactory earth bonding of the unit being filled. This is particularly essential in the cases of trailer filling (see 10.6.2).

8.2.4 Analysis

Product analysis may be provided by one of the following means:

- Portable instruments
- Fixed instruments at each filling location/manifold
- One central analysis room
- A combination of the above

For all types of product analysis the following safety features shall be incorporated:

- A pressure reducing valve (25) to reduce charging pressure down to an acceptable instrument system pressure
- A safety relief valve (26) to protect personnel and instruments in the event of a pressure reducing device failure
- Suitable analytical instruments (27) and systems for use with hydrogen (see 4.7)

8.3 Operating instructions

Detailed operating instructions shall be prepared for each filling station making individual reference to the valves and controls in that system.

The following guidelines should be used in the preparation of the detailed filling instructions.

8.3.1 Cylinder and bundle filling

Ensure that the cylinders are in satisfactory condition for filling.

Check for residual pressure. Cylinders with no residual pressure or returned with open valves shall be put aside for other arrangements, e.g. inspection/evacuation.

Position cylinders at fill manifold.

Connect cylinders to pigtails/hoses.

Open cylinder valves. If venting and/or evacuation are required such as where doubt exists on the residual or depending on product purity requirements, vent to just above atmospheric pressure via the manifold vent valve. Ensure that the vent valve is closed before the pressure is zero gauge, otherwise cylinders and manifold may be subject to atmospheric contamination.

New or retested cylinders having their first fill, shall be evacuated or purged.

Open main isolation valve to fill cylinders, ensuring that all cylinders are of even temperature during filling. Cold cylinders may indicate a blocked cylinder valve, if so then those cylinders should be marked for further investigation.

Leak test cylinder valves and connections during filling.

When cylinders have reached their charging pressure (allowing for temperature correction) close main isolation valve and cylinder valves (*).

Vent manifold pressure.

Analyse product purity where required.

Record analysis and filling pressure if required.

Disconnect cylinders and leak test cylinder valves.

Where labelling is required ensure that labels are correct and intact

8.3.2 Trailer and railcar filling

Present trailer or railcar fill point ensuring that it is; properly secured and that anti-tow away procedures are implemented.

Connect earthing lead to trailer and where necessary to rail car. Connect filling hose(s).

Crack open isolation valve and vent/purge valve in order to purge hose and also to allow analysis of residuals.

Close vent/purge valve. Open main isolation valve to fill container(s). Leak test container valves and connections during filling.

When containers have reached their charging pressure (allowing for temperature correction) close main isolation valve and container valves (*).

Analyse product purity, if required. Record analysis and filling pressure, if required. Vent filling hose Disconnect filling hose and earthing lead, where fitted. Leak test valves.

Ensure trailer or railcar is ready for movement in accordance with the anti tow-away procedures.

(*) NOTE: to avoid dead ending the compressor (where a buffer storage is not provided) it may be necessary to put on line a new bank of containers prior to closing isolation valve on the containers being filled.

9 Storage installations at consumer sites

9.1 Definition

A gaseous hydrogen storage system is an installation in which hydrogen, or mixtures containing hydrogen are stored and discharged to the consumer distribution piping. The system includes stationary vessels, pressure regulators, safety relief devices, manifolds, interconnecting piping and controls. It does not necessarily include storage, systems consisting of bundles or individual cylinders that are taken away for refilling. However for such systems all, or certain aspects, of this code may be applied, depending on the volume of storage.

The storage system terminates at the point where hydrogen, at nominal service pressure, enters the distributing piping.

9.2 Flowsheet Description

The storage system may comprise of high or low-pressure storage vessels, which may be fixed or mobile, or a combination of both.

With the fixed storage system the vessels are recharged in situ. With the mobile storage system, stocks are replenished on a vessel exchange basis.

Where low-pressure storage is to be recharged from a high-pressure source, such as a high-pressure cylinder trailer, a pressure reducing system shall be incorporated, set at a pressure not greater than the design pressure of the low pressure storage vessel(s). This is in addition to any pressure relief devices installed to prevent over-pressure.

The flowsheet in Appendix 4 and the following description applies to a stationary high-pressure storage system, being recharged from a high-pressure cylinder trailer.

Hydrogen from the fixed storage vessel(s) (1) enters the mainline. The storage system shall be provided with a relief valve (2), pressure indicator (3), a manual vent (4) and a storage isolation valve (5).

The hydrogen then enters a pressure reducing station consisting of isolation valves (6) and a pressure regulator (7). This may be a duplicate system, as shown, in order to facilitate maintenance.

A relief valve (8) shall be provided downstream of the pressure reducing station to protect the consumer line and equipment.

A pressure indicator (9) should be provided to indicate pressure in the consumer line.

A non-return valve (10) shall be provided to prevent back flow from the consumer process. The hydrogen then enters the pipeline to the consumer system.

During the recharging operation, hydrogen is fed from the mobile trailer via a flexible hose into the fill connection (11).

A non-return valve (12) shall be provided to prevent storage discharge in the event of a hose failure. This may be incorporated in the fill connection.

A filter (13) may be provided as shown, alternatively filters may be incorporated in the pressure regulators (7) to protect them from solid particles.

A vent valve (14) shall be provided to allow purging of the system, from trailer to inlet isolation valve (15), so that air is prevented from entering the storage system.

The fill line may either be connected directly to the storage vessel (s)/manifold as shown, or may be connected to the mainline between valves (5) and (6).

9.3 Operating instructions

9.3.1 Consumer supply

During the commissioning of the installation, the regulator(s) (7) will have been set to deliver to the consumer, on demand, hydrogen gas at the required pressure. This pressure is indicated by pressure indicator (9).

By the installation of dual storage and regulating systems, arrangements may be made for automatic change-over from depleted to full storage vessel(s).

9.3.2 Filling Instructions

Detailed operating instructions shall be prepared for each consumer station making individual reference to the valves and controls in that filling system.

The following guidelines should be used in the preparation of the detailed filling instructions.

- Present trailer or railcar to fill point ensuring that it is properly secured and anti tow-away safety procedures are implemented.
- Connect earthing leads to trailers and where necessary to railcars.
- Connect filling hose(s).
- Ensure valve (15) is closed and valve (14) is open, crack open trailer isolation valve in order to purge hose.
- Close valve (14).
- Fully open trailer isolation valve.
- Open valve (15) to fill vessel(s)
- Where trailer arrangements allow, cascade decanting is normally used to effect maximum transfer of hydrogen gas to the storage container(s). In this event sequential opening and closing of additional valves, on the trailer, will be required.
- Leak test hose connections.
- When storage vessels have reached their charging pressure or pressure equilibrium has been reached, close main isolation valve (15) and trailer valves.
- Vent fill line via valve (14).Disconnect fill line and earthing lead when fitted.
- Ensure trailer is ready for movement in accordance with the anti tow-away procedures.

9.4 Special considerations

In addition to the requirements contained elsewhere in this Code for hydrogen stations, the following shall also apply to storage installations at consumer sites.

Where the storage installation area is not under the direct control of authorised persons, it shall be contained within a secure, locked enclosure and the key held by an authorised person.

Vessels and hydrogen systems shall be identified in accordance with National or local Standards.

Permanently installed vessels shall be provided with non-combustible supports on firm non-combustible foundations.

The installation should be located outside, where inside location is necessary the conditions of 4.3 shall apply.

All controls necessary for the safe transfer of hydrogen shall be clearly visible from the operator position.

10 Electrical equipment and installations

10.1 General

Hydrogen stations are to be considered as subject to a particular risk of fire and explosion. The degree of risk influences the type of electrical installation.

The installation and operation of electrical systems in hydrogen stations must be in accordance with the Regulations, Standards and Codes of Practice of each country.

10.2 Electrical installation

The electrical installation must be such that, under normal operation, the formation of sparks likely to cause ignition, electrical arcs, or high temperature is precluded. This may be achieved by use of one or more of the types of equipment defined in 10.1.

The type of equipment to be used is dependent on the zone classification. Factors to be considered in determining zone classification include:

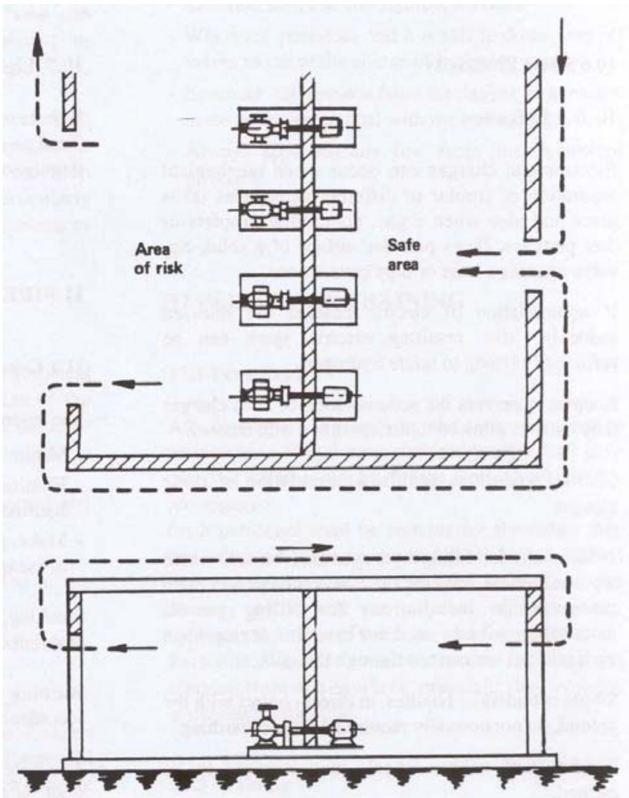
- The possibility of discharge of hydrogen in sufficient quantity to produce an explosive atmosphere.
- The degree and effectiveness of natural ventilation.

Electrical equipment shall be earthed and be placed, if possible, in the low parts of the plant.

Consideration shall be given to the provision of lightning conductors.

FIGURE 1

Shortest possible paths for flammable concentration to pass from area of risk to site of non-flameproof or non-intrinsically safe electrical apparatus shall not be less than 5m.



10.3 System earthing

All systems shall be bonded, where necessary, and effectively earthed to give protection against the hazards of stray electrical currents, static electricity (see 10.6) and lightning protection (see 10.7), in accordance with National Codes/Regulations.

If the electrical equipment is located in a safe area, i.e. outside the hazard zone (see 5), normal electrical equipment can be used, e.g. motors.

Where the drive shaft of a motor projects into a hazard zone, an adequate seal must be fitted (see Figure 1).

10.4 Instruction

Personnel shall be instructed on the dangers of using unauthorised electrical equipment. These instructions shall include advice on hazards, which may arise.

Such instructions should be repeated at regular intervals.

10.5 Inspection

Electrical installations in hazard zones shall be maintained to a high standard.

An inspection shall be carried out at not more than three yearly intervals by a competent person. Records of these inspections shall be kept. Modifications shall only be carried out by competent persons and shall be recorded.

10.6 Static electricity

10.6.1 Definition

Electrostatic charges can occur when mechanical separation of similar or different substances takes place and also when a gas, containing droplets or dust particles, flows past the surface of a solid, e.g. valve openings, hose or pipe connections.

If accumulation of electric charges are released suddenly, the resulting electric spark can be sufficiently strong to ignite hydrogen.

In order to prevent the accumulation of such charges they must be allowed to dissipate in a safe manner.

10.6.2 Precautions against accumulation of static charges

Installations for filling hydrogen into vessels, which are mounted on vehicles, shall have a device to earth these vessels. Installations for filling vessels mounted on rail cars need not have this device when such rail cars are earthed through the rails.

Single cylinders or bundles, in direct contact with the ground do not normally require additional earthing.

Bundles with rubber wheels may require to be earthed.

Driving belts and pulleys of compressors, blowers etc. shall be of conductive material.

Floors, floor coverings, rubber mats, chairs, steps, etc. shall be of conductive material in order to achieve the electrostatic earthing of persons.

All persons working in hydrogen stations should wear conductive footwear.

Care shall also be taken in the choice of material for working clothes since most synthetic materials readily generate static charges. Fire resistant clothing such as Nomex should be worn when working in classified areas.

10.6.3 Inspection

To ensure that the requirements for the prevention of the build up of static electricity on equipment are met, an inspection shall be carried out by a competent person prior to commissioning.

Further inspections shall be carried out at not more than three yearly intervals. Records of these inspections shall be kept.

10.7 Lightning protection

Vessels which are erected in the open require to have fitted a lightning conductor according to National Regulations. Electric resistance shall be < 10 Ohm.

11 Fire protection

11.1 General

The essentials of fire protection are:

- Minimise all potential sources of leaks
- Eliminate, as far as possible, all sources of ignition
- Make provision for isolation of hydrogen, means of escape and methods of controlling any fire

Smoking, fires and open flames of any kind are prohibited with in the distance defined in Table 1.

Warning notices shall be conspicuously posted in accordance with 5.2.

Adequate means of giving alarm in the event of a fire shall be provided. These should be clearly marked and suitably located.

Full emergency procedures shall be established for each particular installation in consultation with local fire authorities and periodic drills should be carried out.

Adequate means of escape in the case of emergency shall be provided. In cases where personnel could be trapped inside compounds or buildings there shall be not less than two separate outward opening exits, remote from each other, strategically placed in relation to the degree of hazard considered.

Emergency exits shall be kept clear at all times.

The area within 3 metres of any hydrogen installation shall be kept free of dry vegetation and combustible matter. If weed killers are used, chemicals such as sodium chlorate, which are a potential source of fire danger, should not be selected for this purpose.

Water shall be available in adequate volume and pressure for fire protection as determined in consultation with the relevant authorities.

Maintenance or repair work shall only be carried out after the relevant parts of the plant, or area, have been checked and a Safety Work Permit has been issued by a competent person. This is particularly important where such maintenance work introduces an ignition hazard, e.g. welding.

11.2 Fire fighting equipment

The location and quantity of fire fighting equipment shall be determined, depending on the size of the hydrogen station and in consultation with the local fire authorities.

The equipment shall be periodically inspected and the inspection date recorded.

Personnel shall be trained in the operation of the equipment provided.

11.3 Action in event of fire

Most hydrogen fires from high-pressure systems originate at the point of discharge and the flame will have the characteristic of a torch or jet. Such fires are extremely difficult to extinguish.

The most effective way to fight a hydrogen fire is to shut off the source of hydrogen supply, provided this can be done safely.

Where hydrogen cannot be isolated, hydrogen fires should not be extinguished whilst the flow of leaking hydrogen is continuing, because of the danger of creating an explosion hazard more serious than the fire itself. Surrounding equipment, when necessary, shall be cooled with water jets or sprays during the fire.

Hydrogen flames are almost invisible and the approach must be made with caution, a flammable material such as paper or cloth affixed to a rod can be used if necessary to detect a flame boundary.

The following are guidelines, which should be used for formulating emergency procedures:

- Raise the alarm
- Summon help and fire fighting services
- Wherever possible, and it is safe to do so, turn off valves to cut off the source of hydrogen supply
- Evacuate all persons from the danger area, except those necessary to deal with the emergency
- Always approach any fire from the windward direction.

12 Personnel training

12.1 Personnel

All personnel engaged in the operation and/or maintenance of hydrogen stations/systems shall have received training suitable for the work on which they are engaged.

Such personnel shall be suitable for the duties they are expected to perform, and shall have satisfied their supervisors that they have understood the training given and are capable of taking any appropriate actions in the event of an emergency.

Personnel should wear conductive footwear and clothing from non-synthetic materials, thus avoiding the build up of static electricity.

12.2 Training

Training shall be arranged to cover all the aspects and potential hazards that the particular operator is likely to encounter.

It shall cover, but not necessarily be confined to, the following subjects for all personnel:

- The potential hazards of hydrogen
- Site safety regulations
- Emergency procedures
- The use of fire fighting equipment
- The use of protective clothing/apparatus including breathing sets where appropriate.

In addition individuals shall receive specific training in the activities for which they are employed.

It is recommended that the training be carried out under a formalised system and that records be kept of the training given and, where possible, some indication of the results obtained, in order to show where further training is required.

The training programme should make provision for refresher courses on a periodic basis.

13 Commissioning

The system shall be checked by a competent person to verify that the construction and equipment conforms with the design drawings and schedules and a report issued to this effect. Particular attention shall be paid to safety/pressure relief devices.

13.1 Testing

13.1.1 Pressure testing

A pressure test shall be carried out in accordance with National or company codes. Means of pressure indication suitable for the test pressure shall be installed before the test. Precautions shall be taken to prevent excessive pressure in the system during the test. Following any hydraulic test, the system/equipment shall be drained and thoroughly dried out and checked.

Where a pneumatic test is specified, dry nitrogen is the preferred test medium. The pressure in the system shall be increased gradually up to the test pressure. Any defects found during the test shall be rectified in an approved manner.

Testing shall be repeated until satisfactory results are obtained.

Pressure tests shall be witnessed by responsible persons and suitable test certificates, signed and issued. Such certificates shall be kept for future reference.

Instruments, gauges, etc. are not normally fitted during the pressure test.

13.1.2 Acoustic emission testing (AET)

In recent years some countries have permitted the replacing of the hydraulic test for medium pressure vessels by an acoustic emission test accompanied by a pneumatic test with a test pressure of between 1,1 to 1,2 times the normal working pressure of the vessel accompanied by on line acoustic emission monitoring or by an acoustic test accompanied by hydraulic test at test pressure.

13.2 Purging

Following the pressure test and prior to the introduction of hydrogen into any part of the system, oxygen shall be eliminated from the system.

This can be achieved by evacuation, purging or pressurising and venting with an inert gas such as nitrogen, and shall be followed by a check to ensure that any residual oxygen is less than 1 %.

Purging procedures should be prepared for each installation, making individual reference to valve and equipment to ensure that all parts of the system are safe for the introduction of hydrogen.

13.3 Start-up

When the above procedures have been satisfactorily completed and all controls and safety devices have been checked, the system is ready for the introduction of hydrogen in accordance with the operating instructions.

When the system is at operating pressure, a further leak test shall be carried out on all joints to ensure tightness under hydrogen conditions. The use of foam producing agents is recommended.

13.4 Operation

Detailed operating instructions containing all necessary technical information in clear form shall be prepared for each system (see 6.3, 7.3, 8.3 and 9.3). These instructions shall be used in the training programme and shall be available to the relevant operating personnel.

Operating personnel shall wear suitable clothing (see 10.6.2) and where necessary protective equipment.

Where single manned operation is used on any part of the plant, adequate means of summoning assistance in the event of an emergency shall be provided. This should be backed up by a system of checks.

14 Maintenance and repairs

A systematic approach to the maintenance of hydrogen systems is necessary to ensure safe and correct operation.

Maintenance/repairs procedures should follow normal sound engineering practice, with additional precautions relating to hazard zones. Special attention shall be paid to ensure that systems are adequately depressurised and purged, before any work is undertaken and a Safety Work Permit is issued (see 5.2).

Detailed maintenance programmes should be prepared for each system, making individual reference to items of equipment in the system. The following guidelines may be used.

14.1 Documentation

A documentation system should be set up to include the following information

- Flowsheets
- Vessel dossiers
- Pressure test certificates
- Operating instructions
- Equipment manufacturers maintenance instructions
- Equipment drawings
- Piping drawings (including any modifications)
- Material schedules
- Modification details and approvals
- List of recommended spare parts

14.2 Records

A suitable system for recording the frequency and extent of all maintenance and periodic tests shall be provided. This should include a means of recording defective or suspect equipment to ensure that prompt and correct action is taken.

Where modifications are made to any part of the system, or to individual items of equipment, these shall be subject to technical approval and conform, at least, to the original standards and be adequately tested.

Any changes made shall be fully documented.

14.3 Schedules

Schedules shall be established detailing maintenance tasks and their frequency. The following shall be included as key items

- Periodic inspection/pressure test of vessels and piping systems
- System checks of leakage
- Safety shut-down system functional check
- Pressure relief device testing
- Control and monitoring equipment testing
- Filter checks
- Electrical system/earthing integrity checks

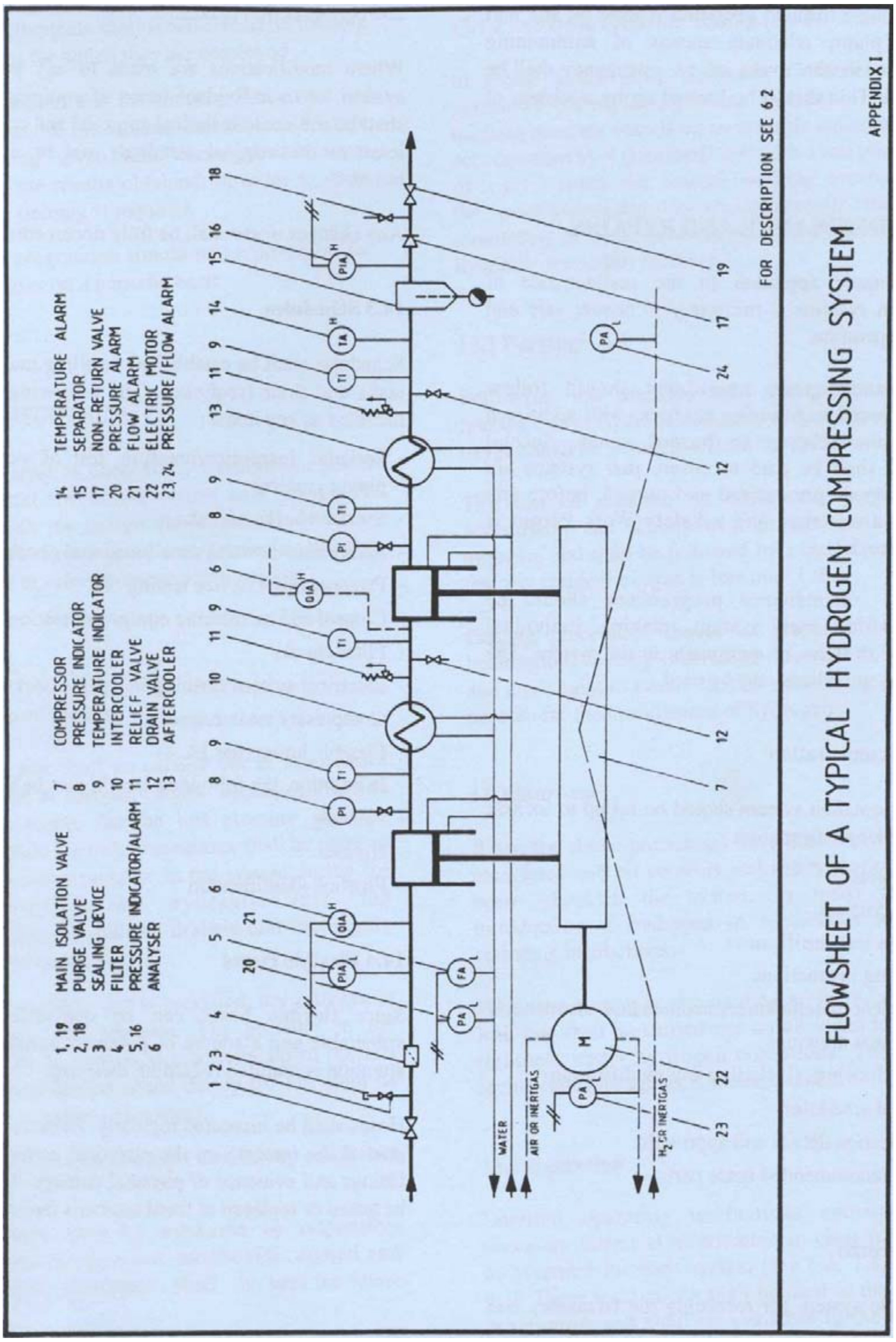
- Compressor maintenance
- Flexible hoses (see 14 .4)
- In addition, the following should also be scheduled
- Painting
- Notices
- Pipeline identification

14.4 Flexible hoses

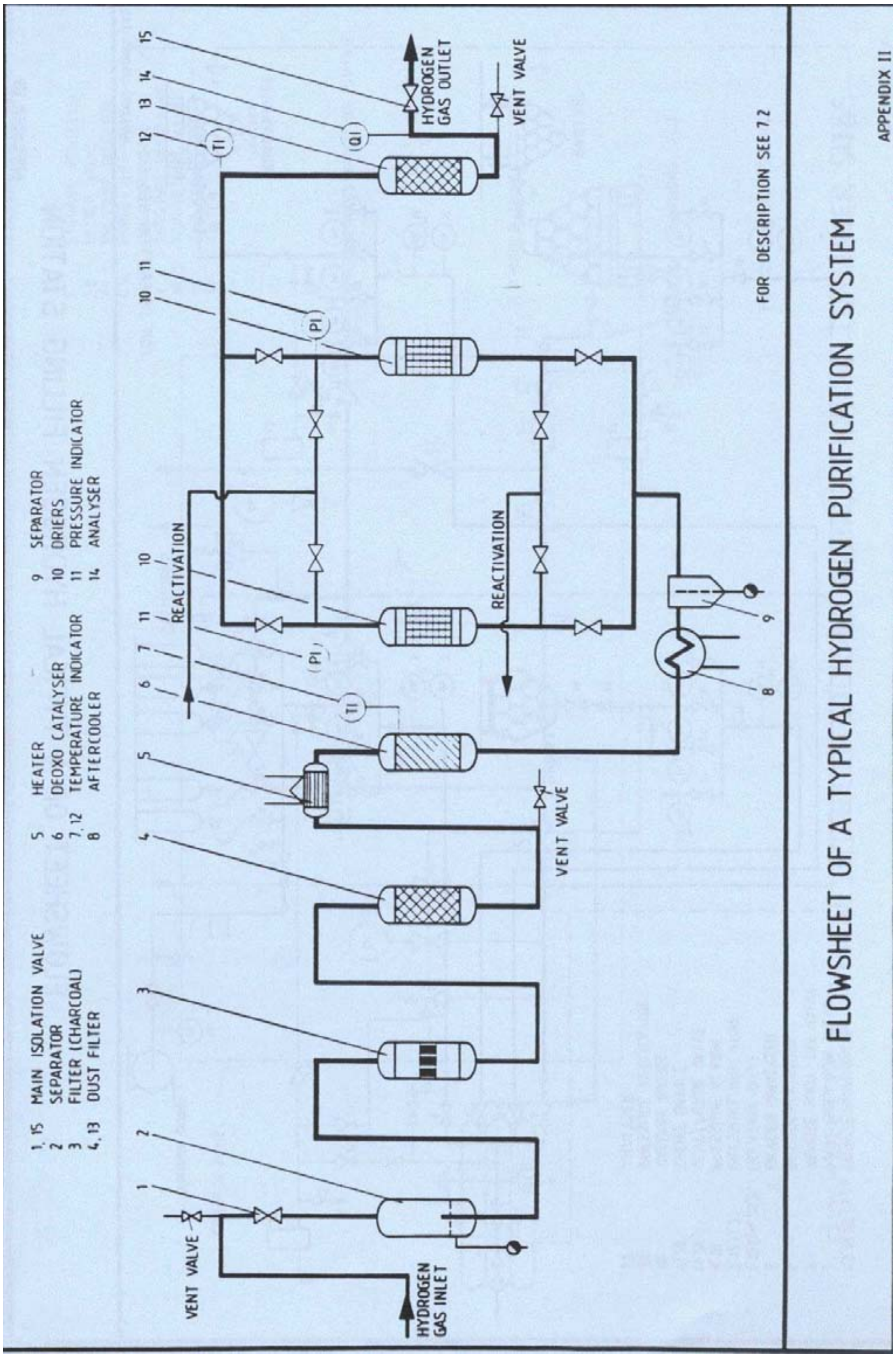
Since flexible hoses can be considered to be vulnerable and a source of potential hazard, special attention is required regarding their use.

Hoses shall be inspected regularly. Attention shall be paid to the integrity of the electrical continuity, end fittings and evidence of physical damage. They shall be tested or replaced at fixed intervals (see also 4.6).

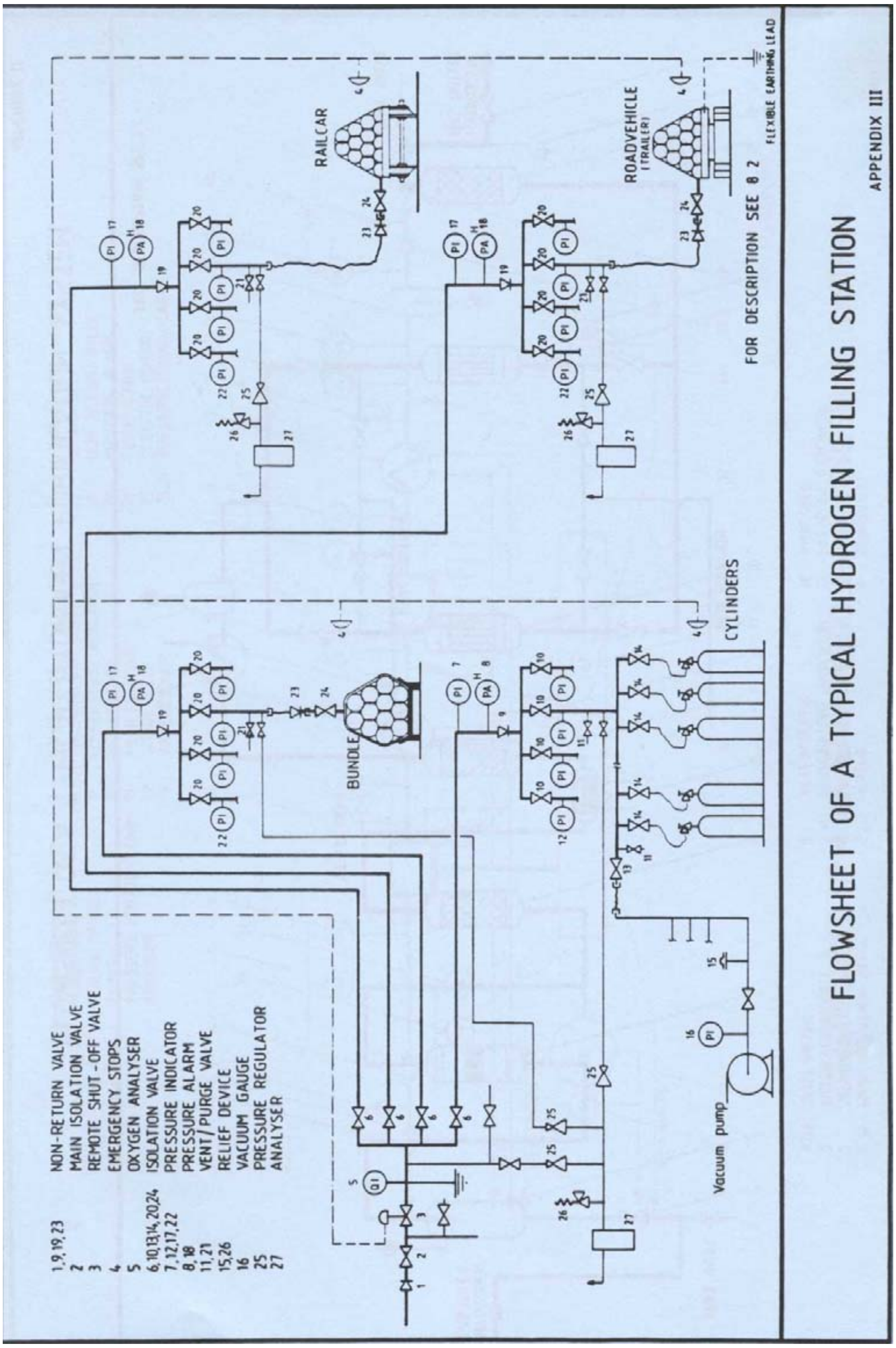
Appendix 1: Flowsheet of a typical hydrogen compressing system



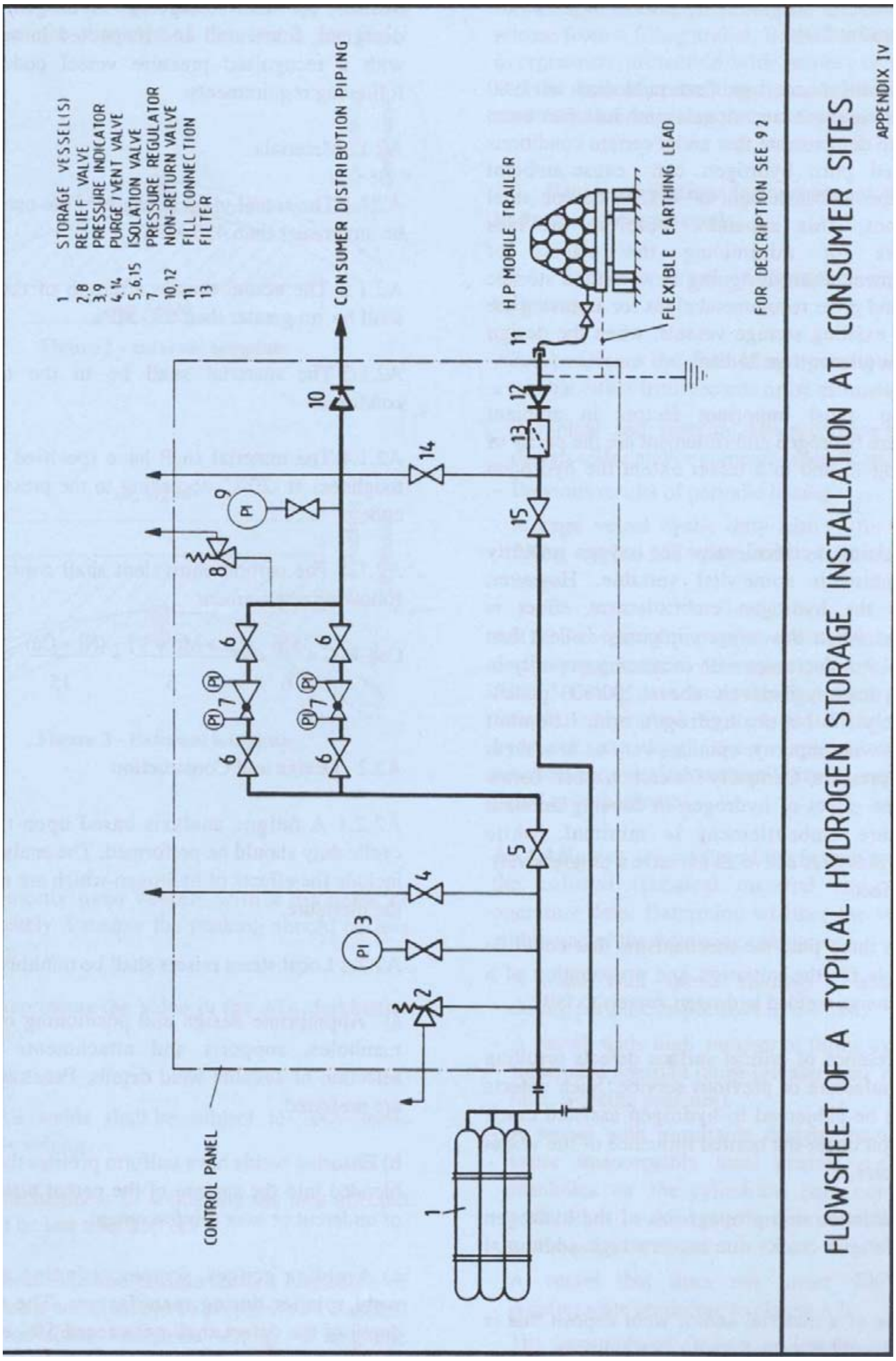
Appendix 2: Flowsheet of a typical hydrogen purification system



Appendix 3: Flowsheet of a typical hydrogen filling system



Appendix 4: Flowsheet of a typical storage installation at consumer sites



Appendix 5: Welded gaseous hydrogen storage vessels

1. Introduction

Sufficient research and operations data has been reported to demonstrate that under certain conditions pressurised hydrogen can cause ambient temperature embrittlement of welded carbon steel fabrications. This appendix therefore provides guidelines for minimising the effects of embrittlement when designing new welded storage vessels and gives recommendations for assessing the safety of existing storage vessels, when the design pressure is greater than 25 bar.

The two most important factors in ambient temperature hydrogen embrittlement are the purity of the hydrogen, and to a lesser extent the hydrogen pressure.

In determining a critical value for oxygen impurity the literature is somewhat variable. However, generally the hydrogen embrittlement effect is maximised when the oxygen impurity is less than 10 ppm/V, but decreases with increasing impurity to the extent that oxygen levels above 200/300 ppm/V completely inhibit the hydrogen embrittlement effect. As with impurity, opinions vary as to what is a critical pressure. Generally for carbon steels below 10 bar, the effect of hydrogen in causing ambient temperature embrittlement is minimal, while hydrogen pressures above 25 bar have a progressively greater effect.

There are three possible mechanisms that could be responsible for the initiation and propagation of a defect, causing welded hydrogen vessels to fail:

a. The presence of critical surface defects resulting from manufacture or previous service. Such defects may then be subjected to hydrogen assisted crack propagation under the normal influence of the vessel filling cycles.
b. The initiation and propagation of the hydrogen assisted fatigue cracks due to very high additional local stresses.
c. The use of a material and/or weld deposit that is highly susceptible to hydrogen embrittlement.

2. Guidelines for the design of hydrogen storage vessels.

Vessels for the storage of hydrogen shall be designed, fabricated and inspected in accordance with a recognised pressure vessel code and the following requirements:

2.1 Materials

2.1.1 The actual yield strength of the material shall be no greater than 420 MPa.

2.1.2 The actual tensile strength of the material, shall be no greater than 630 MPa.

2.1.3 The material shall be in the normalised condition.

2.1.4 The material shall have specified values for toughness at -20°C. according to the pressure vessel codes.

2.1.5 The carbon equivalent shall conform to the following requirement

$$Ceq = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{Ni + Cu}{15} < 0.45$$

2.2 Design and Construction

2.2.1 A fatigue analysis based upon the design cyclic duty should be performed. The analysis should include the effects of hydrogen which are reported in the literature.

2.2.2 Local stress raisers shall be minimised by:

a. Appropriate design and positioning of nozzles, manholes, supports and attachments and the selection of suitable weld details. Penetration welds are preferred.
b. Ensuring welds have uniform profiles that are well blended into the surface of the parent plate and free of undercut or over reinforcement.
c. Avoiding gouges, scrapes, grinding marks and weld splatter during manufacture. The maximum depth of the defect shall not exceed 5% of the wall thickness.
d. Employing plate rolling techniques that minimise peaking. (Peaking is a deviation from the truly circular shape that occurs at welds due to an inability to roll to the plate edge. The allowable peaking depends on the diameter of the vessel, see Fig. 1 and 2).

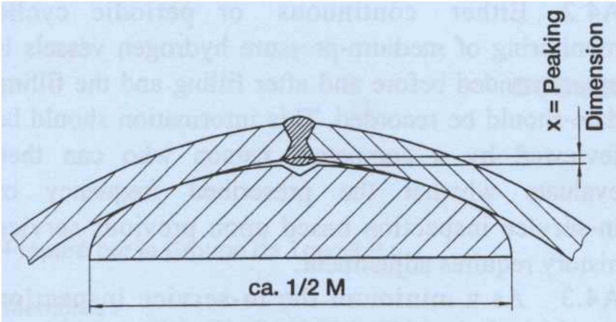


Figure 1 – Internal template

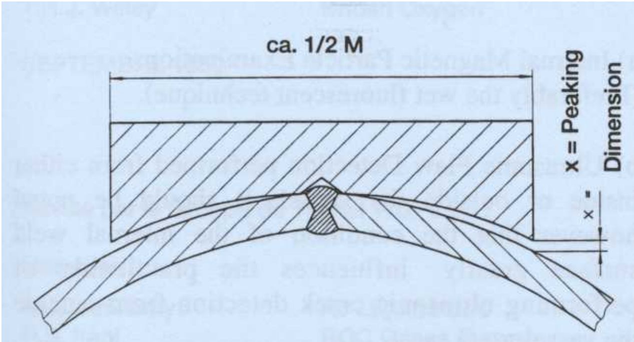


Figure 2 – External template

For commonly used vessels with a diameter of approximately 3 metres the peaking should be less than 4 mm (*).

* 4 mm represents the value in the AD-Merkblätter in Germany

2.2.3 All welds shall be subject to 100% non-destructive testing.

2.2.4 The hardness of welds and the heat-affected zone shall be less than 250 HV

2.2.5 The inside and outside surface conditions of all main seam welds should be prepared to a standard suitable for either ultrasonic testing or magnetic particle inspection.

2.2.6 The vessel should be protected by suitable overpressure protection adequately sized for all foreseeable events, including an uncontrolled gas release from a filling trailer. Both the position of the overpressure protection with respect to the vessel and the sizes of connecting lines shall be taken into account when designing the protection system.

3. Recommendations for assessment of existing hydrogen storage vessels

3.1 For each vessel in operation perform the following

3.1.1 Obtain the following operational data as available either from records or by estimation

- Technical and material data according to national design codes and/or company specification.
- Previous results of periodic testing
- Storage vessel cyclic duty history for number of filling cycles and magnitude of service pressure range.

3.1.2 Review of pressure vessel construction and design in particular to determine local stress raisers.

3.1.3 Using data from the literature perform a fatigue analysis taking account of the effects of hydrogen, the local stress situation and where practical the material susceptibility to embrittlement based upon hardness.

3.1.4 Review the results of the fatigue analysis and the collated technical material and historical operating data and determine whether the vessel falls within one of the following categories ;

- A vessel with special findings of abnormalities during periodic inspections in the past.
- A vessel with high number of filling cycles and a significant pressure range (greater than 65% of the max. working pressure).
- A vessel with unsuitable design features, which cause unacceptable local stresses, e.g. flanges, manholes in the cylindrical part, compensation pads other welded attachments or reinforcements on the pressure vessel.
- A vessel that does not meet the material requirements according to clause 2.
- The accumulated fatigue cycles are greater than half the allowable design cycles following from a fatigue analysis according to clause 3.1.3.

3.1.5 For those vessels falling within the categories listed in 3.1.4 above, perform non-destructive testing of the main seams and any other identified suspect areas by an appropriate method. Some acceptable non-destructive testing techniques are specified in 4.3.

Also measure the deviation in geometrical shape in the vicinity of the longitudinal main seams. Differentiate between ovality and peaking and determine the local stresses due to each type of deviation. (Note 1)

Note 1 - In Germany peaking measurements were performed on all existing vessels following a FAD instruction. It is EIGA's prevailing opinion that this is only necessary when one of the conditions in 3.1.4 applies.

3.1.6 Dependent on the failure analysis and the results of the non-destructive testing the suitability of the hydrogen storage vessel for further operation can be determined as follow:

- Without any restrictions
- With reduced service pressure or pressure range
- With decreased retest periods
- With reduced number of pressure cycles
- Unsuitable for further service

4. In Service Inspection and Cyclic Monitoring

4.1 As recommended in 4.3, medium-pressure hydrogen storage vessels should be subjected to periodic in-service inspections. The frequency of these inspections should be determined by the cyclic duty of the vessels when compared to the design cyclic life and the periodic inspection requirements of the national regulatory authorities.

4.2 Either continuous or periodic cyclic monitoring of medium-pressure hydrogen vessels is recommended before and after filling and the filling date should be recorded. This information should be reviewed by a competent person who can then evaluate whether the prescribed frequency of in-service inspection based upon previous service history requires adjustment.

4.3 As a minimum the in-service inspection should include 100% NDT of all main weld seams by an appropriate method capable of ensuring that all small internal surface cracks typically 3 mm long by 1 mm deep, will be detected. Such methods are:

a) Internal Magnetic Particle Examination. (Preferably the wet fluorescent technique).
b) Ultrasonic Flaw Detection performed from either inside or outside the vessel. It should be noted however that the condition of the internal weld surface greatly influences the practicality of performing ultrasonic crack detection from outside the vessel.
c) Pressure testing in conjunction with Acoustic Emission. All local acoustic activity will require evaluation by (a) or (b) above.

4.4 The term weld seam shall be taken to mean the weld seam itself plus the heat affected zone. Typically a band 50 mm wide will suffice.