Co-funded by the
Erasmus+ Programme
of the European Union

HYSKILLS

Module 3-

Hydrogen high pressure fittings & connections

Piping systems, fittings, threads and tubing and for H2

Learning Outcomes

Hydrogen piping system

- ✓ Underground piping system
- ✓ Above-ground piping systems

Underground piping system

- ✓ Must be all welded
- ✓ Externally coated to protect against soil corrosion
- ✓ Must be adequately buried to protect it from frost, casual surface construction, shifting due to unstable soil, back fill damage to the external surface of pipe or the coating, and aboveground loads such as vehicles or equipment moving over the path of the pipeline
- ✓ If casing is required (such as under railroad), it should avoid avoid cathodic protection problems and arcing.
- ✓ These cracks may also allow hydrogen to pass through the material surface into the surrounding area posing potential safety risks as well as contamination in some systems.

Piping should be of all welded construction in accordance with a specification and inspection code such as API 1104. Underground piping must be externally coated to an approved specification, to protect against soil corrosion. Reference to current, internationally accepted, coatings standards and specifications is recommended. Underground piping should be adequately buried to protect it from frost, casual surface construction, shifting due to unstable soil, back fill damage to the external surface of pipe or the coating, and aboveground loads such as vehicles or equipment moving over the path of the pipeline. Pipe casings or load shields, if required by special agencies, should be installed at railroad or road crossings or where unusual aboveground loading can occur. Casings or sleeves require careful consideration and special measures to avoid cathodic protection problems and arcing, which can be caused due to an electrical connection forming between the sleeve and carrier pipe due to settlement, etc. In general, the use of metallic casings or sleeves is to be avoided wherever possible. Underground hydrogen piping is vulnerable to damage by lightning strikes or ground fault conditions, which may rupture the pipe material. To reduce the likelihood of one of these occurring, electrical continuity between underground hydrogen piping and above ground piping, or other metal structures, should be avoided.

Above-ground piping systems

- ✓ Welded joints are recommended wherever is possible.

- ✓ Should be painted to protect against atmospheric corrosion.
- ✓ Above-ground portions of pipeline systems should connect to underground portions through an electrically insulated joint to isolate the underground cathodic protection system and follow specific standards and criteria such as: The electrical resistance to earth of the installed pipeline should not exceed 10 Ω for personnel protection against electrical or high voltage shock.
- ✓ Piping should not be exposed to external forces which can cause a failure or dangerous situation such as external impingement from hot gas or steam vents, vibration from external sources, leaking oil dripping onto the line, etc.
- ✓ Should be periodically inspected for corrosion and leakage.

Above-ground portions of pipeline systems should connect to underground portions through an electrically insulated joint to isolate the underground cathodic protection system .All above-ground pipelines shall have electrical continuity across all connections, except insulating flanges, and shall be earthed at suitable intervals to protect against the effects of lightning and static electricity. The electrical resistance to earth of the installed pipeline should not exceed 10 ohms for personnel protection against electrical or high voltage shock. Flange bolting will provide the necessary electrical bond provided the bolts are not coated with a dielectric material or paint and are well maintained to avoid rust. In the case of short above ground sections, where insulating flanges are not used, the pipe should be insulated from the support structure by means of an isolating pad. Hydrogen piping should not be exposed to external forces which can cause a failure or dangerous situation such as external impingement from hot gas or steam vents, vibration from external sources, leaking oil dripping onto the line, etc. Above-ground piping systems outside plant fence lines may be subject to deliberate or accidental damage. Consideration should be given to installing pipe and valves below ground, with extensions for above ground operators and instrumentation.

Example of H_2 pipeline proposal in the UK

Possible sources of hazards:

Thermal radiation from sustained fire and shock pressure from gas cloud explosion!

• Damage by third parties

• Use of non-compatible materials and equipment at all operating conditions

• Hydrogen embrittlement

• External corrosion due to improper cathodic protection

• Leaks at valve packing, gaskets,..

• Over pressurisation of the pipeline

• Improper inerting procedure

• Improper operation and maintenance of the pipeline

• Abnormal loads due to land slide, floods, earthquakes, crossing of roads, railways, ..

• Influence of other structures, such as high power electrical lines, electrical railways

• Damage due to an abnormal event on a parallel pipe

• Road accident or fire in the vicinity of above ground parts of the pipeline

• The radiation of a vent fire or a flare

Some level of risk is inherent in all human activities and positive steps should be taken to reduce the risks to a reasonable level whenever this is possible. Every new transportation pipeline system must be designed, constructed and operated in such a way that the additional risk to people, property and the environment is kept within acceptable limits. To this end, a safety analysis should be performed on every new pipeline system or significant modification to an existing system. The safety analysis is a proven way to assess the risks of the pipeline system to the environment, the risks to the pipeline from its environment, as well as to define the measures, to be applied during design, construction and operation, to reduce the probability of occurrence and the consequences of abnormal events. Normally, the level of detail of the safety analysis is based on the population density around the pipe route, the potential severity of an incident, and the likelihood an incident could occur. The method typically used in a safety evaluation is to determine the individual risk and to show that it is within acceptable limits. It is not unusual to define individual risk, as the probability of a person remaining at a given open-air location at all times being fatally injured as a result of any abnormal event affecting the pipeline and to give an acceptable limit in terms of fatalities per number of years. Local regulations often provide guidelines on performing safety analysis and specify acceptable limits.

Example of mitigating measures:

- *Control of third party interference*
- *Increased thickness of the pipe*
- *Non-destructive test on welds*
- *Pipeline marking*
- *Isolation valves*

- *Excess flow or low pressure shut down valves*
- *Leak detection by mass balance*
- *Deepen the pipeline*
- *Physical protections: concrete coating or encasement, concrete slabs*
- *Rerouting pipelines*
- *Reducing pipeline operating pressure*
- *Operating procedures, including: inspection programs, corrosion control programs,*
- *emergency plan, personnel training, information of third parties, collaboration with local authorities*

Measures for risk management

- ✓ Defining Risk zones
- ✓ Identifying risk Criteria
- ✓ siting

Within the distances of concern found by the simulation, the zoning shall be studied for the whole length of the pipe, to identify points where compensatory measures should be considered. Another widely used method to define the zone around the pipe that could be affected by a leak or rupture is using a potential impact radius.

The risk criteria taken into account depend on the governing national or local regulations.

Siting of hydrogen systems must be carefully studied, especially at points where venting to atmosphere may occur, for example valve stations, vents, drains, safety valves, etc. The location of potential vent sites should be chosen with care and, in so far as is practical, to avoid the immediate proximity of vulnerable areas and equipment such as electrical equipment, flammable product storage tanks, public roads, public buildings, car parks and transfer stations. Siting and safety distances should follow established practices and applicable regulations.

Venting as a safety measure

- The flammability and auto ignition potential of hydrogen gas is a significant potential risk factor. Hence venting should follow safety instructions.

Venting methods:

- Venting to atmosphere
- Destruction in a flare

Venting to atmosphere

- ✓ Very large flows of hydrogen gas may be vented directly to atmosphere at a safe outdoor location. When large quantities of hydrogen must be vented to atmosphere, it is recommended to first perform a dispersion study to guide the vent design. Venting to atmosphere is most commonly used along the length of the pipe line since a flare is usually not available.

- ✓ To minimize the possibility of auto ignition when the hydrogen leaves the stack, it is recommended that the piping immediately upstream of the exit be made either of stainless steel or a non-sparking metallic material.
- ✓ In some occasions, purging of the vent line with an inert gas such as nitrogen may help to prevent auto ignition,

Destruction in a flare

- Unless a steady flow of hydrogen is continually vented, flaring is not recommended. Flaring requires a constant velocity and controls to ensure that the flare is not extinguished and air is not allowed to backflow into the vent stack.
- In certain emergency or maintenance situations, hydrogen can also be flared. For example, a safety feature in some hydrogen-powered vehicles is that they can flare the fuel if the tank is on fire, burning out completely with little damage to the vehicle, in contrast to the expected result in a gasoline-fuelled vehicle.

- 

Material Specification for pipeline

**Materials suitable for industrial pipeline is listed in GR-2.2.1-1

Co-funded by the Erasmus+ Programme of the European Union

Table GR-2.1.1-2 Material Specification Index for Pipelines

Spec. No.	Grade	Description
ASTM		
A53	A	Electric resistance welded, seamless 30,000 psi
A53	B	Electric resistance welded, seamless 35,000 psi
A106	A	Seamless 30,000 psi
A106	B	Seamless 35,000 psi
A106	C	Seamless 40,000 psi
A135	A	Electric resistance welded 30,000 psi
A135	B	Electric resistance welded 35,000 psi
A139	A	Electric fusion welded 30,000 psi
A139	B	Electric fusion welded 35,000 psi
A139	C	Electric fusion welded 42,000 psi
A139	D	Electric fusion welded 46,000 psi
A139	E	Electric fusion welded 52,000 psi
A333	1	Seamless, electric resistance welded 30,000 psi
A333	6	Seamless, electric resistance welded 35,000 psi
A333	10	Seamless, electric resistance welded 65,000 psi
A381	...	Class Y-35 double submerged-arc welded 35,000 psi
A381	...	Class Y-42 double submerged-arc welded 42,000 psi
A381	...	Class Y-46 double submerged-arc welded 46,000 psi
A381	...	Class Y-48 double submerged-arc welded 48,000 psi
A381	...	Class Y-50 double submerged-arc welded 50,000 psi
A381	...	Class Y-52 double submerged-arc welded 52,000 psi
A381	...	Class Y-56 double submerged-arc welded 56,000 psi
A381	...	Class Y-60 double submerged-arc welded 60,000 psi
A381	...	Class Y-65 double submerged-arc welded 65,000 psi [Note (1)]
API		
API 5L	A	Electric resistance welded, double submerged-arc welded 30,000 psi
API 5L	B	Electric resistance welded, seamless, double submerged-arc welded 35,000 psi
API 5L	X42	Electric resistance welded, seamless, double submerged-arc welded 42,000 psi
API 5L	X52	Electric resistance welded, seamless, double submerged-arc welded 52,000 psi
API 5L	X56	Electric resistance welded, seamless, double submerged-arc welded 56,000 psi
API 5L	X60	Electric resistance welded, seamless, double submerged-arc welded 60,000 psi
API 5L	X65	Electric resistance welded, seamless, double submerged-arc welded 65,000 psi [Note (1)]
API 5L	X70	Electric resistance welded, seamless, double submerged-arc welded 70,000 psi [Note (1)]
API 5L	X80	Electric resistance welded, seamless, double submerged-arc welded 80,000 psi [Note (1)]

(a) The maximum operating pressure (MOP) shall not exceed 3,000 psi for all materials unless otherwise noted, provided the material suitably is demonstrated by tests in hydrogen, such as per Article KD-10 of ASME BPV Code Section VIII, Division 3. (b) Grades containing Ni additions above 0.50 shall not be used. (c) See Mandatory Appendix II for reference dates of specifications. NOTE: (1) MOP shall be less than 1,500 psi.

Welding considerations

- *Cleaning of Component Surfaces*

- *Joint Preparation and Alignment*

  Preparation of Pipe Component Ends

  Alignment for Welding
- *Weld reinforcement*
- *Preheating for weldments*
- *Post-weld Heat Treatment*

Table GR-3.4.6-1 Weld Reinforcement

Wall Thickness, $\overline{T}_w$, mm (in.) [Note (1)]	Height, mm (in.) [Note (2)]
≤ 6 (1/4)	≤ 1.5 (1/16)
> 6 (1/4) and ≤ 13 (1/2)	≤ 3 (1/8)
> 13 (1/2) and ≤ 25 (1)	≤ 4 (5/32)
> 25 (1)	≤ 5 (3/16)

Internal and external surfaces to be thermally cut or welded shall be cleaned to remove paint, oil, rust, scale, grease, slag, oxides, and other deleterious material that would be detrimental to the base metal.

Preheating is used, along with heat treatment, to minimize the detrimental effects of high temperature and severe thermal gradients inherent in welding. The necessity for preheating and the temperature to be used shall be specified in the engineering design and demonstrated by procedure qualification.

Heat treatment is used to avert or relieve the detrimental effects of high temperature and severe temperature gradients inherent in welding and to relieve residual stresses created by bending and forming.

Pipeline and piping support

The layout and design of piping and its supporting elements shall be directed toward preventing the following: (a) piping stresses in excess of those permitted in this Code (b) leakage at joints (c) excessive thrusts and moments on connected equipment (such as pumps and turbines) (d) excessive stresses in the supporting (or restraining) elements (e) resonance with imposed or fluid-induced vibrations (f) excessive interference with thermal expansion and contraction in piping which is otherwise adequately flexible (g) unintentional disengagement of piping from its supports (h) excessive piping sag in piping requiring drainage slope (i) excessive distortion or sag of piping subject to creep under conditions of repeated thermal cycling (j) excessive heat flow, exposing supporting elements to temperature extremes outside their design limits. In general, the location and design of pipe-supporting elements may be based on simple calculations and engineering judgment. However, when a more refined analysis is required and a piping analysis, which may include support stiffness, is made, the stresses, moments, and reactions determined thereby shall be used in the design of supporting elements.

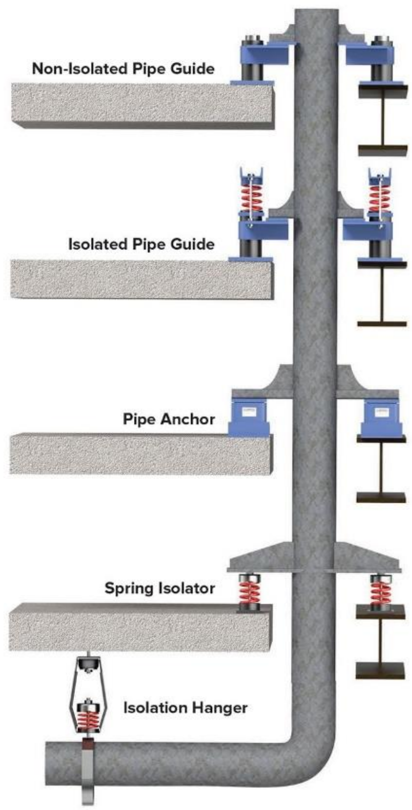
Fixtures and supports

(a) **Anchors and Guides**

(1) A supporting element used as an anchor shall be designed to maintain an essentially fixed position.

(2) To protect terminal equipment or other (weaker) portions of the system, restraints (such as anchors and guides) shall be provided, where necessary, to control movements or to direct expansion into those portions of the system which are designed to absorb them. The design, arrangement, and location of restraints shall ensure that expansion joint movements occur in the directions for which the joint is designed. In addition to the other thermal forces and moments, the effects of friction in other supports of the system shall be considered in the design of such anchors and guides.

(3) Piping layout, anchors, restraints, guides, and supports for all types of expansion joints shall be designed in accordance with Appendix X, para. X301.2 of ASME B31.3.

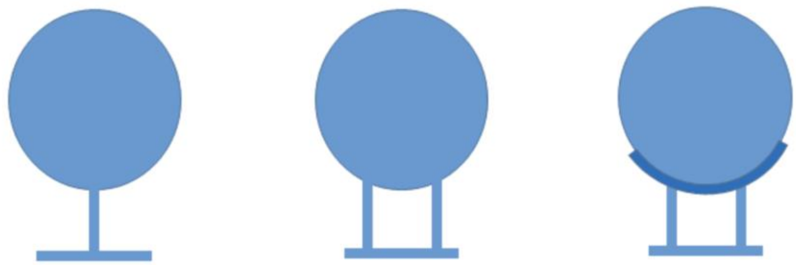


(b) Inextensible Supports Other Than Anchors and Guides

(1) Supporting elements shall be designed to permit the free movement of piping caused by thermal expansion and contraction.

(2) Hangers include pipe and beam clamps, clips, brackets, rods, straps, chains, and other devices. They shall be proportioned for all required loads. Safe loads for threaded parts shall be based on the root area of the threads.

(3) Sliding supports (or shoes) and brackets shall be designed to resist the forces due to friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the expected movement of the supported piping.



Examples of Shoe supports   Shoe support with saddle

(c) Resilient Supports

(1) Spring supports shall be designed to exert a supporting force, at the point of attachment to the pipe, equal to the load as determined by weight balance calculations. They shall be provided with means to prevent misalignment, buckling, or eccentric loading of the springs, and to prevent unintentional disengagement of the load.

(2) Constant-support spring hangers provide a substantially uniform supporting force throughout the range of travel. The use of this type of spring hanger is advantageous at locations subject to appreciable movement with thermal changes. Hangers of this type should be selected so that their travel range exceeds expected movements.

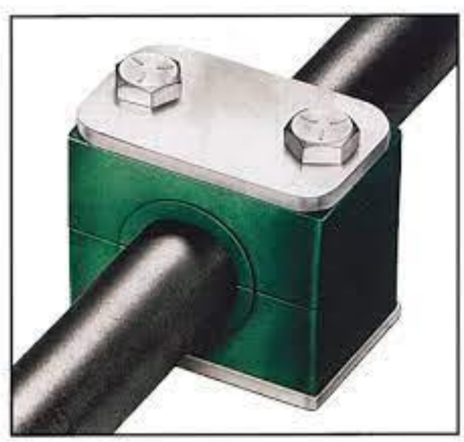
(3) Means shall be provided to prevent overstressing spring hangers due to excessive deflections. It is recommended that all spring hangers be provided with position indicators.

(d) Counterweight Supports

Counterweights shall be provided with stops to limit travel. Weights shall be positively secured. Chains, cables, hangers, rocker arms, or other devices used to attach the counterweight load to the piping shall be subject to the requirements of (b) above.

(e) Hydraulic Supports

An arrangement utilizing a hydraulic cylinder may be used to give a constant supporting force. Safety devices and stops shall be provided to support the load in case of hydraulic failure.



Heating methods for heat treatment

Furnace Heating: Fuel gas or electric shall be allowed.

(1) Heating an assembly in a furnace should be used when practical; however, the size or shape of the unit or the adverse effect of a desired heat treatment on one or more components, where dissimilar materials are involved, may dictate alternative procedures.

(2) An assembly may be post-weld heat treated in more than one heat in a furnace, provided there is at least a 300 mm (1 ft) overlap of the heated sections and the portion of the assembly outside the furnace is shielded so that the temperature gradient is not harmful.

(3) Direct impingement of flame on the assembly is prohibited.

Local Heating: Fuel gas, electrical induction, or resistance shall be allowed.

(1) Welds may be locally PWHT by heating a circumferential band around the entire component with the weld located in the centre of the band. The width of the band heated to the PWHT temperature for girth welds shall be at least three times the wall thickness at the weld of the thickest part being joined.

(2) For nozzle and attachment welds, the width of the band heated to the PWHT temperature shall extend beyond the nozzle weld or attachment weld on each side at least two times the header thickness and shall extend completely around the header.

(3) Where the nozzle or attachment weld heating band includes a girth weld or a bent or formed section, the heat band shall extend at least 25 mm (1 in.) beyond the ends thereof.

Post-weld heat treatment heating and Cooling Requirements

Above 335°C (600 °F), the rate of heating and cooling shall not exceed 335 °C /h (600 °F /hr) divided by one half the maximum thickness of material in inches at the weld, but in no case shall the rate exceed 335 °C /h (600 °F /hr). The cooling cycle shall provide the required or desired cooling rate and may include cooling in a furnace, still air, by application of local heat or insulation, or by other suitable means.

Preheat temperatures

Table GR-3.5-1 Preheat Temperatures

Base Metal P-No. or S-No. [Note (1)]	Base Metal Group	Nominal Thickness [Note (2)] mm	Nominal Thickness [Note (2)] in.	Specified Min. Tensile Strength, Base Metal MPa	Specified Min. Tensile Strength, Base Metal ksi	Min. Preheat Temperature Required [Note (3)] °C	Min. Preheat Temperature Required [Note (3)] °F
1	Carbon steel	< 25	< 1	≤ 490	≤ 71	80	175
		≥ 25	≥ 1	All	All	80	175
		All	All	> 490	> 71	80	175
3	Alloy steels, Cr ≤ ½%	< 13	< ½	≤ 490	≤ 71	80	175
		≥ 13	≥ ½	All	All	80	175
		All	All	> 490	> 71	80	175
4	Alloy steels, ½% < Cr ≤ 2%	All	All	All	All	150	300
5A, 5B	Alloy steels, 2¼% ≤ Cr ≤ 9Cr max.	All	All	All	All	175	350
Note (4)	Nonferrous	All	All	All	All	24	75

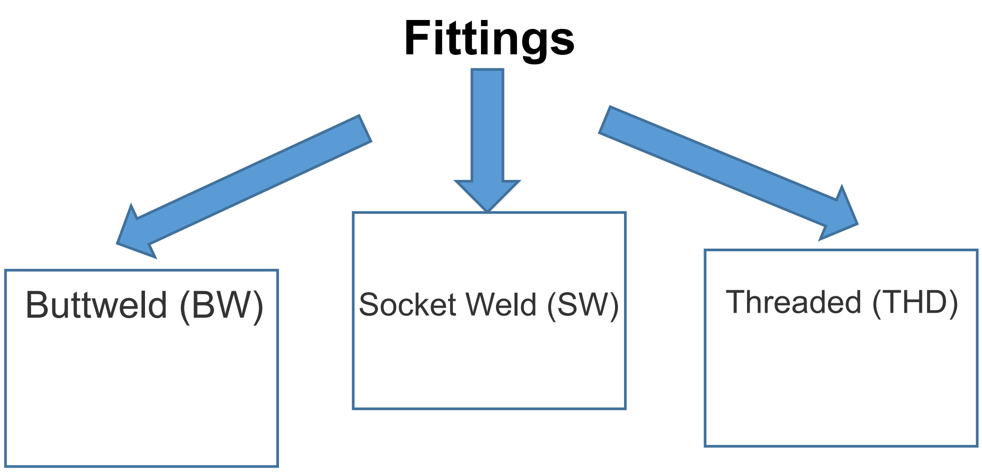
Post-weld treatment temperatures

Table GR-3.6.1-1 Requirements for Postweld Heat Treatment of Weldments

Base Metal P-No. or S-No. [Note (1)]	Base Metal Group	Nominal Thickness [Note (2)]		Specified Min. Tensile Strength, Base Metal		Metal Temperature Range		Holding Time: Nominal Wall [Note (3)]		Holding Time: Min. Time,
		mm	in.	MPa	ksi	°C	°F	min/mm	hr/in.	hr
1	Carbon steel	≤ 20	≤ 3/4	All	All	None	None	...	...	...
		> 20	> 3/4	All	All	595–650	1,100–1,200	2.4	1	1
3	Alloy steels, Cr ≤ 1/2%	≤ 20	≤ 3/4	≤ 490	≤ 71	None	None	...	...	...
		> 20	> 3/4	All	All	595–720	1,100–1,325	2.4	1	1
		All	All	> 490	> 71	595–720	1,100–1,325	2.4	1	1
4 [Note (4)]	Alloy steels, 1/2% < Cr ≤ 2%	≤ 13	≤ 1/2	≤ 490	≤ 71	None	None	...	...	...
		> 13	> 1/2	All	All	705–745	1,300–1,375	2.4	1	1
		All	All	> 490	> 71	705–745	1,300–1,375	2.4	1	1
5A, 5B [Note (4)]	Alloy steels (2 1/4% ≤ Cr ≤ 10%)									
	≤ 3% Cr and ≤ 0.15% C	≤ 13	≤ 1/2	All	All	None	None	...	...	...
	≤ 3% Cr and ≤ 0.15% C	> 13	> 1/2	All	All	705–760	1,300–1,400	2.4	1	1
	> 3% Cr or > 0.15% C	All	All	All	All	705–760	1,300–1,400	2.4	1	1
8	High alloy steels, austenitic	All	All	All	All	None	None	...	...	...

Fittings

A pipe fitting is defined as a part used in a piping system, for changing direction, branching or for change of pipe diameter, and which is mechanically joined to the system. There are many different types of fittings and they are the same in all sizes and schedules as the pipe.



Butt Weld Fittings

Co-funded by the
Erasmus+ Programme
of the European Union


Elbow 90deg. LR


Elbow 45deg. LR


Elbow 90deg. SR


Elbow 180deg. LR


Elbow 180deg. SR


Tee EQ


Tee Reducing


Reducer Concentric

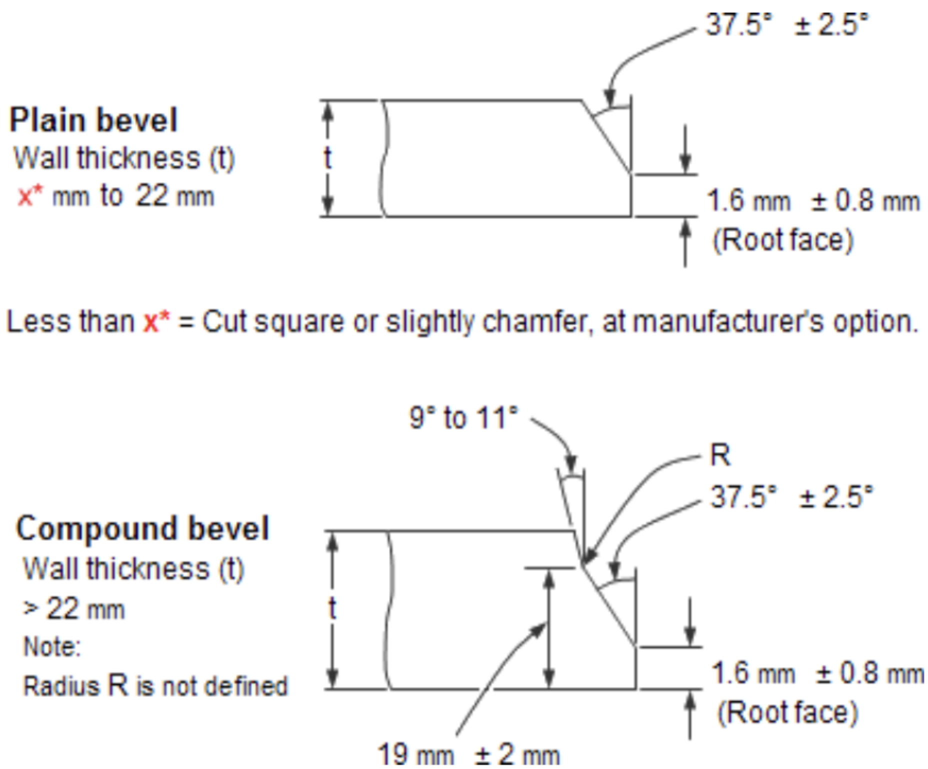

Reducer Eccentric


End Cap


Stub End ASME B16.9


Stub End MSS SP43

- The ends of all butt-weld fittings are beveled, exceeding wall thickness 4 mm for austenitic stainless steel, or 5 mm for ferritic stainless steel. The shape of the bevel depending upon the actual wall thickness. This beveled ends are needed to be able to make a 'Butt weld'.
- ASME B16.25 covers the preparation of butt-welding ends of piping components to be joined into a piping system by welding. It includes requirements for welding bevels, for external and internal shaping of heavy-wall components, and for preparation of internal ends (including dimensions and dimensional tolerances). These weld edge preparation requirements are also incorporated into the ASME standards (e.g., B16.9, B16.5, B16.34).



- Butt-weld (BW) fittings whose dimensions, dimensional tolerances et cetera are defined in the ASME B16.9 standards. Light-weight corrosion resistant fittings are made to MSS SP43.

A piping system using butt-weld fittings has many inherent advantages over other forms such as:

- Welding a fitting to the pipe means it is permanently leak-proof
- The continuous metal structure formed between pipe and fitting adds strength to the system
- Smooth inner surface and gradual directional changes reduce pressure losses and turbulence and minimize the action of corrosion and erosion
- A welded system utilizes a minimum of space

Socket Weld Fittings

A Socket Weld is a pipe attachment detail in which a pipe is inserted into a recessed area of a Valve, fitting or flange. In contrast to butt-weld fittings, Socket Weld fittings are mainly used for small pipe diameters (Small Bore Piping); generally for piping whose nominal diameter is NPS 2 or smaller.

To join pipe to Valves and fittings or to other sections of pipe, fillet-type seal welds be used. Socket Welded Joints construction is a good choice wherever the benefits of high leakage integrity and great structural strength are important design considerations. Fatigue resistance is lower than that in butt-welded construction due to the use of fillet welds and abrupt fitting geometry, but it is still better than that of most mechanical joining methods.

SW Fittings are family of high pressure fittings are used in various industrial processes.

- They are used for lines conveying flammable, toxic or expensive material where no leakage can be permitted, and for steam 300 to 600 PSI.
- They are used only in conjunction with ASME Pipe and are available in the same size range.

- They are used in areas where pipe-work is permanent and are designed to provide good flow characteristics.
- They are are produced to several ASTM standards and are manufactured in accordance with ASME B16.11. The B16.11 standard covers pressure-temperature ratings, dimensions, tolerances, marking, and material requirements for forged carbon and alloy steel. Acceptable material forms are forgings, bars, seamless pipe, and seamless tubes which conform to the fittings chemical requirements, melting practices, and mechanical property requirements of ASTM A105, A182, or A350.
- They are available in three pressure ratings.. Class 3000, 6000 and 9000

Socket Weld Fittings

Pros:

- The pipe need not be bevelled for weld preparation.
- Temporary tack welding is no needed for alignment, because in principle the fitting ensures proper alignment.
- The weld metal can not penetrate into the bore of the pipe.
- They can be used in place of threaded fittings, so the risk of leakage is much smaller.
- Radiography is not practical on the fillet weld; therefore correct fitting and welding is crucial. The fillet weld may be inspected by surface examination, magnetic particle (MP), or liquid penetrant (PT) examination methods.
- Construction costs are lower than with butt-welded joints due to the lack of exacting fit-up requirements and elimination of special machining for butt weld end preparation.

Socket Weld Fittings

Cons:

- The welder should ensure for an expansion gap of 1/16 inch (1.6 mm) between de pipe and the shoulder of the socket. ASME B31.1 para. 127.3 Preparation for Welding (E) Socket Weld Assembly says.. In assembly of the joint before welding, the pipe or tube shall be inserted into the socket to the maximum depth and then withdrawn approximately 1/16" (1.6 mm) away from contact between the end of the pipe and the shoulder of the socket.
- The expansion gap and internal crevices left in socket welded systems promotes corrosion and make them less suitable for corrosive or radioactive applications where solids build up at the joints may cause operating or maintenance problems. Generally require butt welds in all pipe sizes with complete weld penetration to the inside of the piping.
- Socket welding are unacceptable for UltraHigh Hydrostatic Pressure (UHP) in Food Industry application since they do not permit full penetration and leave overlaps and crevices that are very difficult to clean, creating virtual leaks.

The purpose for the bottoming clearance in a Socket Weld is usually to reduce the residual stress at the root of the weld that could occur during solidification of the weld metal, and to allow for differential expansion of the mating elements.

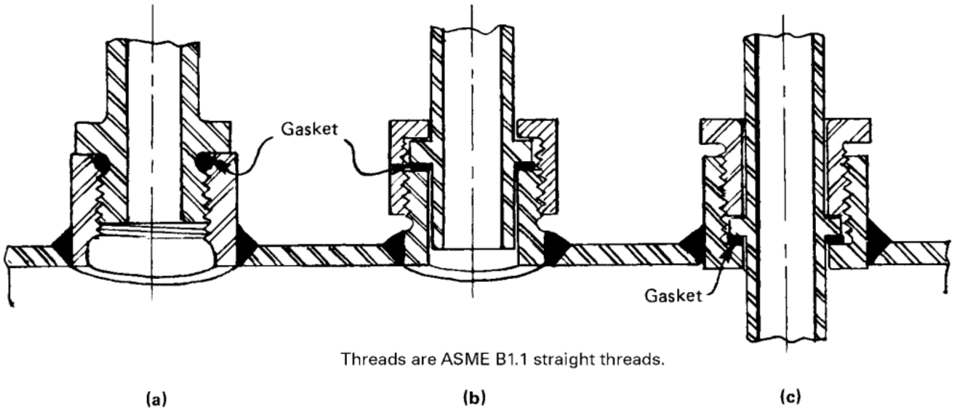
Threads in pipelines, valves and fittings

Threaded connections shall be kept to an absolute minimum. However ever if not avoidable:

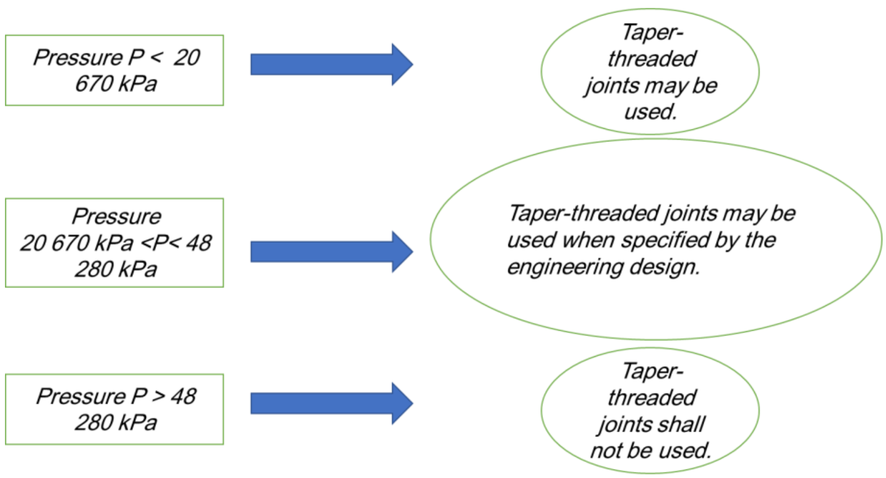
- Threaded reducing bushings should not be used in pressure/ flow control facilities where they are subject to high-frequency piping vibrations.
- Threaded joints with a suitable thread seal are acceptable for use in gaseous hydrogen systems but are to be avoided in liquid hydrogen systems if possible.
- If threaded joints must be used in liquid hydrogen systems, the male and female threads should be tinned with a 60% lead–40% tin solder, then heated to provide a soldered joint with pipe thread strength.
- Thread Sealants. Taper-threaded joints with suitable thread sealants are acceptable for hydrogen gas inside buildings.
- Provision should be made to counteract forces that would tend to unscrew taper-threaded joints.
- Threaded joints with a suitable thread seal are acceptable for use in gaseous hydrogen systems but are to be avoided in liquid hydrogen systems if possible.
- If threaded joints must be used in liquid hydrogen systems, the male and female threads should be tinned with a 60% lead–40% tin solder, then heated to provide a soldered joint with pipe thread strength.
- Thread Compound or Lubricant. Any compound or lubricant used on threads shall be suitable for the service conditions and shall not react with either the service fluid or the piping material.
- A threaded joint to be seal welded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal welded in accordance with following paragraph and provided all compound is removed from exposed threads:

Seal welding taper-threaded joints should be considered for hydrogen gas inside buildings. Taper-threaded joints shall not be seal welded unless the composition of the metals in the joint is known and proper procedures for those metals are followed. Thread sealants shall not be used and the weld material shall cover the full circumferential length of the thread.

- Threaded joints in which the tightness of the joint is provided by a seating surface other than the threads, e.g., a union comprising male and female ends joined with a threaded union nut, or other constructions shown typically as below, may be used.



Taper threaded joints



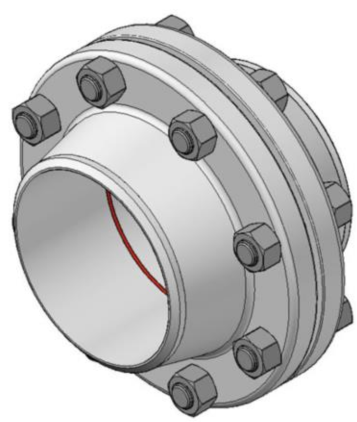
Pressure design of straight-threaded joints shall be based on calculations consistent with design requirements of this Code. These calculations shall be substantiated by testing in accordance with to-be-determined procedures and protocols. The testing shall consider such factors as assembly and disassembly, cyclic loading, vibration, shock, hydrogen embrittlement, thermal expansion and contraction, and other factors to be determined.

Flanged joints

A flange is a method of connecting pipes, valves, pumps and other equipment to form a piping system. It also provides easy access for cleaning, inspection or modification. Flanges are usually welded or screwed. Flanged joints are made by bolting together two flanges with a gasket between them to provide a seal.

Bolted Flange connections

A bolted flange connection is a complex combination of many factors (Flange, Bolts, Gaskets, Process, Temperature, Pressure, and Medium). All these various elements are interrelated and depend upon one another to achieve a successful result. The reliability of the flanged joint depends critically upon competent control of the joint making process.



Special flange joints

Orifice flange

Orifice Flanges are used with orifice meters for the purpose of measuring the flow rate of either liquids or gases in the respective pipeline. Pairs of pressure "Tappings", mostly on 2 sides, directly opposite each other, are machined into the orifice flange. This makes separate orifice carriers or tappings in the pipe wall unnecessary.

Orifice Flanges generally come with either Raised Faces or RTJ (Ring Type Joint) facings. They are, for all intensive purposes, the same as weld neck and slip on flanges with extra machining.

Orifice flange

Anchor Flange

An anchor flange is a device that is installed on a pipeline to counteract axial movement, and prevents the pipeline from moving. Once the flange is attached (welded) to the pipe, the flange is usually anchored to a concrete foundation.

The anchor flange not only prevents axial movement, but is also installed when the pipeline crosses a bridge or river. Over a long distance, the pipe with huge liquid tends to sink.

The use of anchor flanges on both sections of the pipeline secures the position of the pipe.

One of the common characteristics of a metal pipeline is the inherent movement caused by the flow of fluid through the pipe, as well as by the expansion and contraction caused by temperature changes. When a pipeline makes a sharp turn, the fluid flow in the pipeline attempts to push the pipe in the direction of the flow. By placing an anchor flange on the pipeline and securing it in place by locking it into a concrete pillar buried deep in the ground, the forces pushing against the pipe are transferred to the earth.

For large diameter, high pressure and long distance pipelines, anchor flanges act as important supporting elements. They are usually placed underground or buried.

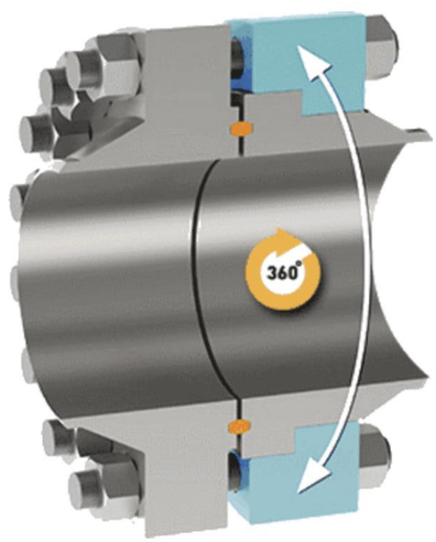
Swivel Ring Flange

The Swivel Ring Flange is comparable to a set of stub end and lap joint flange, with the difference that an Swivel Ring Flange is used for higher pressure and mostly in offshore / subsea applications.

The swivel ring flanges adjust for bolt hole misalignment in the field via rotational adjustment of the bolt hole pattern on the flange ring relative to the spool piece.

The Swivel Ring Flange is of two piece construction consisting of a heavy forged welding hub with a rotating forged ring that serves as a mating flange to a Weld Neck or other flange. It has a Retaining Ring to secure the Welding Hub to hold the Rotating Ring in position.

These versatile flanges are utilized in many applications and are used extensively in offshore piping where they solve the issues associated with the alignment of bolt holes during subsea flange installation.

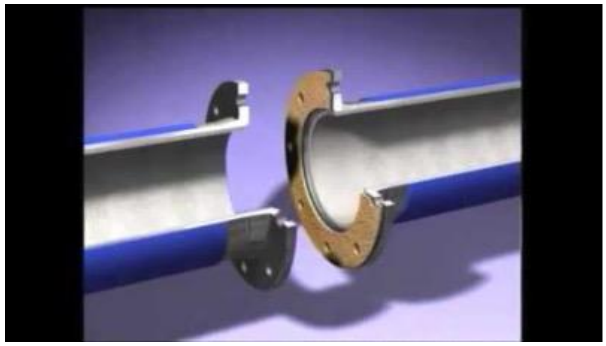


360° rotational swivel ring simplify bolt alignment

Flanged joints

The following factors should be considered for leak-free flanged joints:

- service conditions, e.g., external loads, bending moments, and thermal insulation
- flange rating, type, material, facing, and facing finish design for access to the joint
- condition of flange mating surfaces
- joint alignment and gasket placement before bolt up
- specifications for tightening bolts



Flange facings and gaskets

- ✓ Flange facings shall be suitable for the intended service and for the gaskets and bolting employed.
- ✓ Gaskets shall be selected so that the required seating load is compatible with the flange rating, facing, strength of the flange, and bolting.
- ✓ Gasket materials shall be suitable for the service conditions. Gasket materials not subject to cold flow should be considered for temperatures significantly above or below ambient.
- ✓ Use of full-face gaskets with flat faced flanges should be considered when using gasket materials subject to cold flow for low pressure and vacuum services at moderate temperatures. When such gasket materials are used in other fluid services, the use of tongue and groove or other gasket-confining flange facings should be considered.
- ✓ The effect of flange facing finish should be considered in gasket material selection.

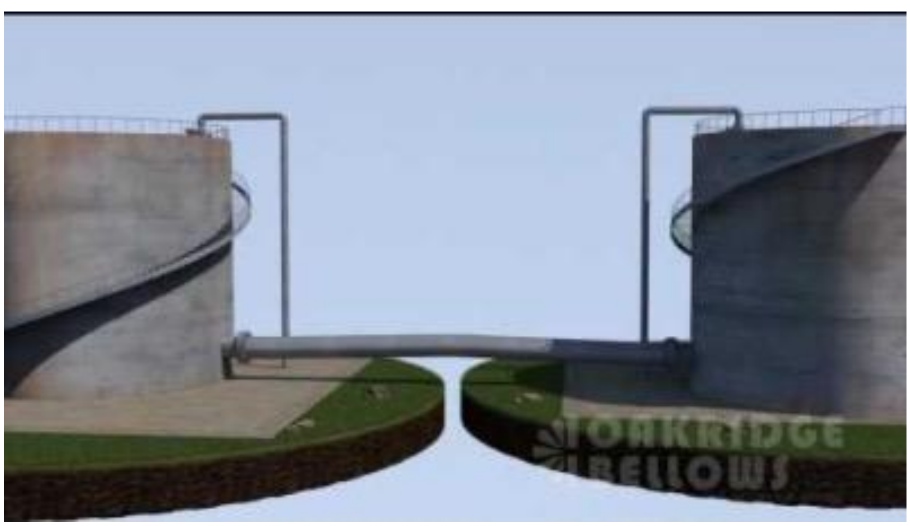
Co-funded by the
Erasmus+ Programme
of the European Union

Considerations for flange bolting

- The use of controlled bolting procedures should be considered in high, low, and cycling temperature services, and under conditions involving vibration or fatigue, to reduce the potential for joint leakage due to differential thermal expansion and the possibility of stress relaxation and loss of bolt tension.
- If stress relaxation and loss of bolt tension is possible due to thermal cycling, bolt hardware shall be strain hardened.
- Bolting selected shall be adequate to seat the gasket and maintain joint tightness under all design conditions.
- Bolting having not more than 207 MPa (30 ksi) specified minimum yield strength shall not be used for flanged joints rated ASME B16.5 Class 400 and higher, nor for flanged joints using metallic gaskets, unless calculations have been made showing adequate strength to maintain joint tightness.
- Except where limited by other provisions of this Code, carbon steel bolting may be used with nonmetallic gaskets in flanged joints rated ASME B16.5 Class 300 and lower for bolt metal temperatures at −29°C to 204°C (−20°F to 400°F), inclusive. If these bolts are galvanized, heavy hexagon nuts, threaded to suit, shall be used.
- Tapped holes for flange bolts shall be of sufficient depth that the thread engagement will be at least seven eighths of the nominal thread diameter.

Expansion joints

- *Adequate means shall be provided to prevent separation of the joint. Safeguarding is required.*
- *Consideration shall be given to the tightness of expanded joints when subjected to vibration, differential expansion or contraction due to temperature cycling, or external mechanical loads.*



Expansion Joints

Expansion joints are used in piping systems to absorb thermal expansion or terminal movement where the use of expansion loops is undesirable or impractical. Expansion joints are available in many different shapes and materials. However, for hydrogen piping systems it should be metallic expansion joint.

Metallic Expansion Joints are installed in pipe work and duct systems to prevent damage caused by thermal growth, vibration, pressure thrust and other mechanical forces. There is a wide range of metallic bellows designs in a variety of materials. Options range from the simplest convoluted bellows used in petroleum refineries. Materials include all types of stainless steels and high grade nickel alloy steels.

Any pipe connecting two points is subjected to numerous types of action which result in stresses on the pipe. Some of the causes of these stresses are:

- internal or external pressure at working temperature
- weight of the pipe itself and the parts supported on it
- movement imposed on pipe sections by external restraints
- thermal expansion

Hinged Metal Expansion Joints

Hinges are mounted to limit the expansion joint to absorb movements in only one plane in the hinged metal expansion joints. Due to the hinges the expansion joint is not able to absorb axial movement. The hinge is likewise designed to protect the bellow from torsion. These movement limiters reduce the loads from the pressure thrust force and the temperature of the pipeline.

The pressure thrust force from the media is in this way absorbed in the pipeline. The hinges are designed to absorb a larger part of the pressure than the expansion joint is able to absorb. In this way the expansion joint is relieved and at the same time limited to absorb only the movement it is designed for. Further the hinges are designed to support the loads from pipes and connected equipment, wind stresses and other external induced stresses that add external loads to the pipeline.

Co-funded by the
Erasmus+ Programme
of the European Union

Single Hinged Metal Expansion Joint

The main mission of the Hinged metal expansion joint (simple metal expansion joint for 1-axis for angular movement SSA and SFA) is to absorb angular expansion movements with rotation on a single axis both thermal and mechanical origin.

This hinged expansion joints or simple metal expansion joint for 1-axis is composed of a single bellow of several waves in the form of 'U'.

These waves are made by one or more metal sheets longitudinally welded and shaped hydraulically or mechanically.

Due to its configuration, the designer must bear in mind that these models DO NOT transmit pressure stresses to the fixed points and guides of the piping system.

Metal expansion joint for one axis angular movement with welding ends

Co-funded by the
Erasmus+ Programme
of the European Union

Metal expansion joint for one axis angular movement with fixed flanges

Double Hinged Metal Expansion Joint

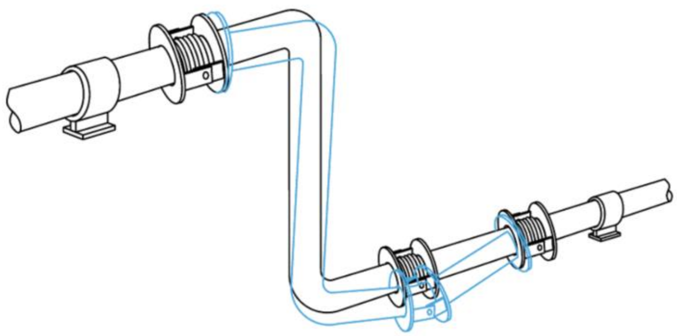
The main mission of the double hinged metal expansion joint is to absorb angular and lateral expansion movements with rotation on a single axis both thermal and mechanical origin.

The double hinged metal expansion joint (universal metal expansion joint for one plane) is composed of two bellows of several waves in the form of 'U'. These waves are made by one or more metal sheets longitudinally welded and shaped hydraulically or mechanically.

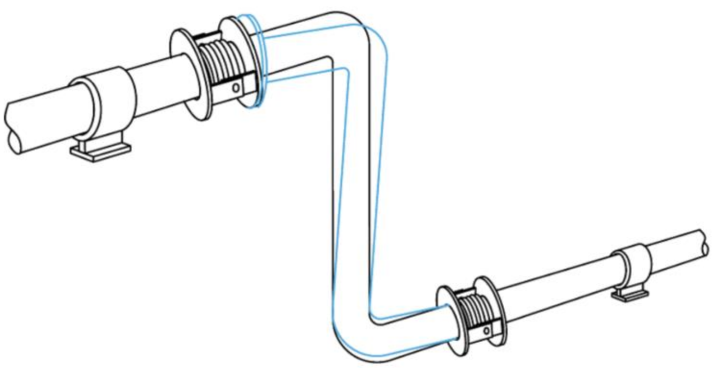
Due to its configuration, the designer must bear in mind that these models DO NOT transmit pressure stresses to the fixed points and guides of the piping system.

Co-funded by the
Erasmus+ Programme
of the European Union

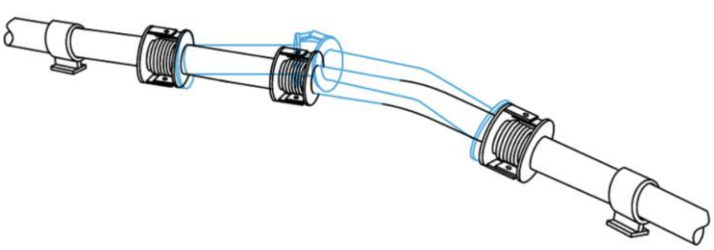
Examples of applications:



FOR STRAIGHT PIPE RUNS USING MAXIMUM CENTER-TO-CENTER DISTANCE BETWEEN PIPES. A THIRD UNIT CATERS FOR EXPANSION OF OFFSET AND MAINTAINS THE TWO PARALLEL RUNS IN ALIGNMENT. USE THREE SINGLE HINGED BELLOWS.

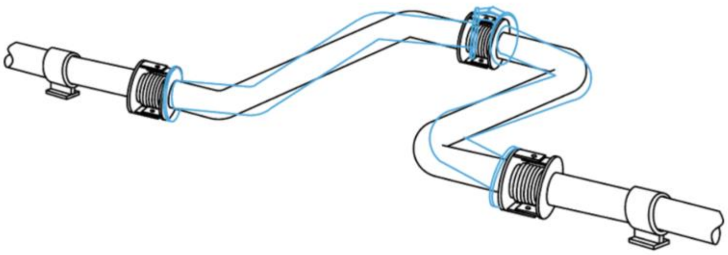


FOR STRAIGHT RUNS, USING MAXIMUM CENTER-TO-CENTER DISTANCE BETWEEN PIPE CENTERS USE TWO SINGLE HINGE BELLOWS.

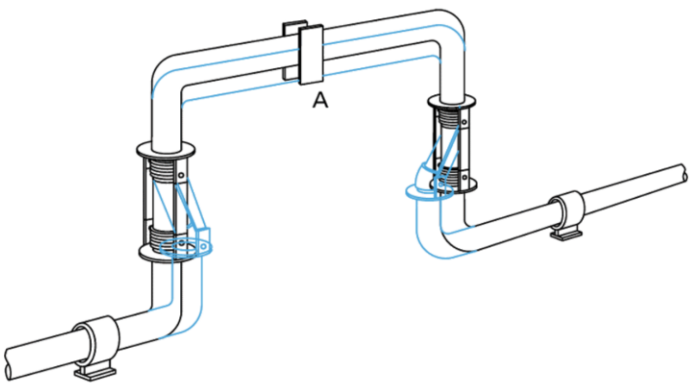


FOR TAKING EXPANSION IN TWO DIRECTIONS FROM TWO PIPES AT AN ANGLE GREATER THAN 90, USE THREE SINGLE HINGED BELLOWS.

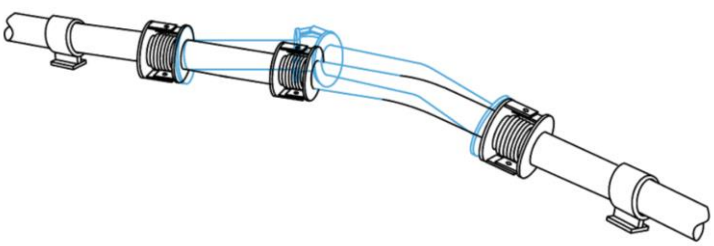
Co-funded by the
Erasmus+ Programme
of the European Union



FOR TAKING UP EXPANSION IN VERY LONG STRAIGHT PIPE RUNS. USE THREE SINGLE HINGED BELLOWS.

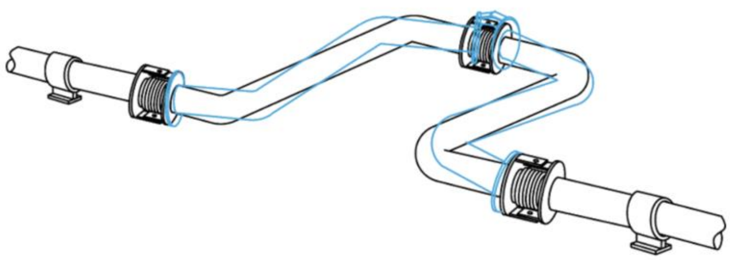


FOR TAKING UP EXPANSION IN LONG STRAIGHT PIPE RUNS. USE TWO DOUBLE HINGED BELLOWS WITH DIRECTIONAL ANCHOR AT 'A'.

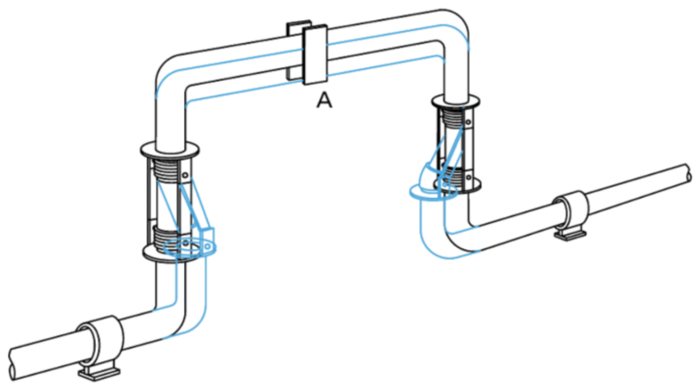


FOR TAKING EXPANSION IN TWO DIRECTIONS FROM TWO PIPES AT AN ANGLE GREATER THAN 90, USE THREE SINGLE HINGED BELLOWS.

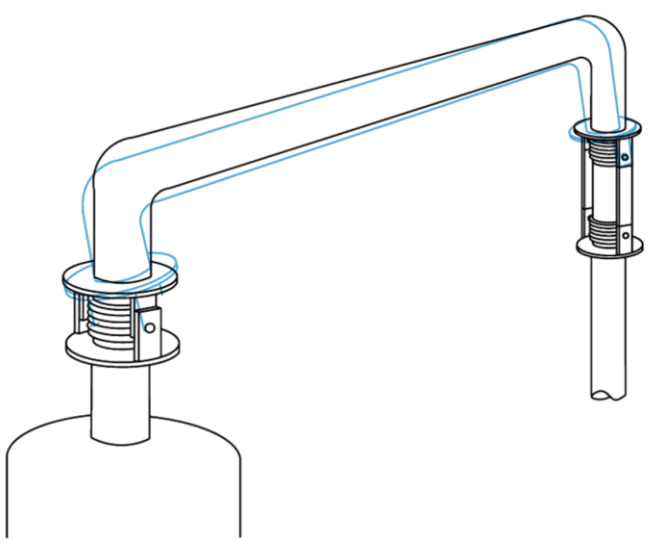
Co-funded by the
Erasmus+ Programme
of the European Union



FOR TAKING UP EXPANSION IN VERY LONG STRAIGHT PIPE RUNS. USE THREE SINGLE HINGED BELLOWS.

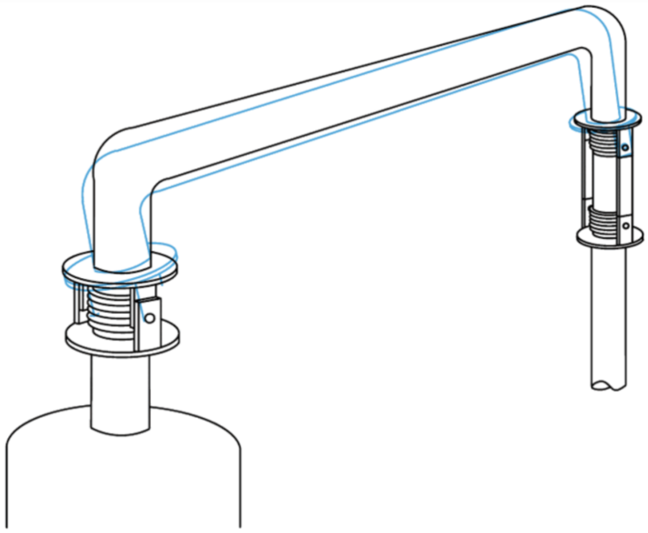


FOR TAKING UP EXPANSION IN LONG STRAIGHT PIPE RUNS. USE TWO DOUBLE HINGED BELLOWS WITH DIRECTIONAL ANCHOR AT 'A'.

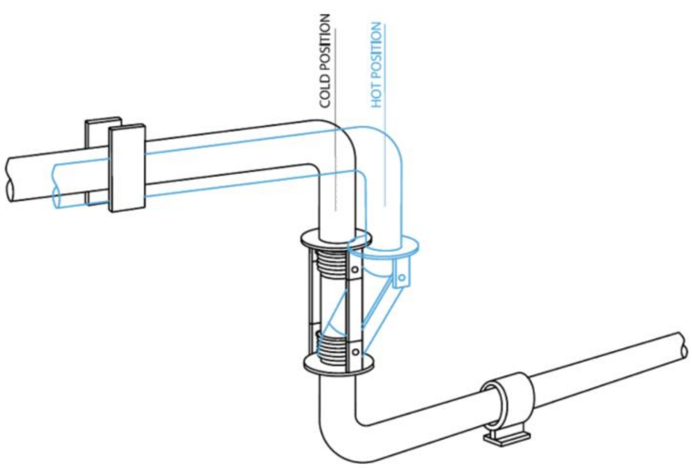


FOR PIPE BETWEEN TWO VESSELS OR OTHER MACHINERY USE DOUBLE HINGED BELLOWS AND SINGLE HINGED BELLOW.

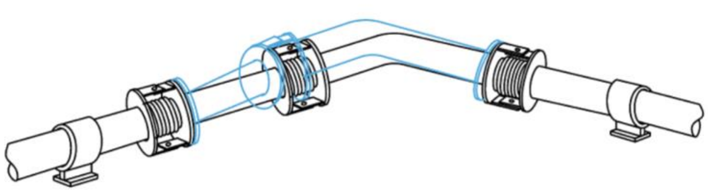
Co-funded by the
Erasmus+ Programme
of the European Union



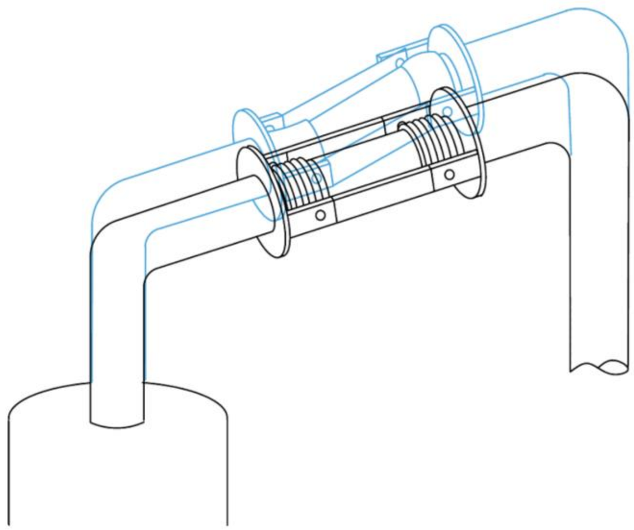
FOR PIPE BETWEEN TWO VESSELS OR OTHER MACHINERY USE DOUBLE HINGED BELLOWS AND SINGLE HINGED BELLOW.



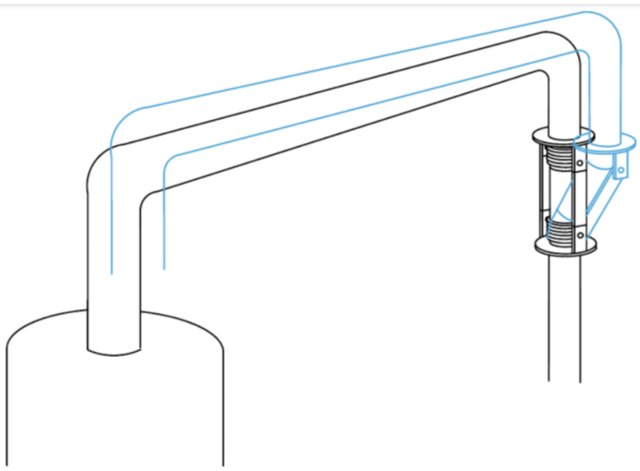
WHERE THERE IS AVAILABLE OFFSET IN LONG STRAIGHT PIPE RUN, USE DOUBLE HINGED BELLOWS.



FOR TAKING EXPANSION IN TWO DIRECTIONS FROM TWO PIPE RUNS AT 90, USE THREE SINGLE HINGED BELLOWS.



FOR PIPE UP THE SIDE OF A VESSEL, A CROSS OVER BETWEEN TWO VESSELS, OR OTHER MACHINERY, USE DOUBLE HINGED BELLOWS WHERE VERTICAL PIPE IS VERY SHORT.



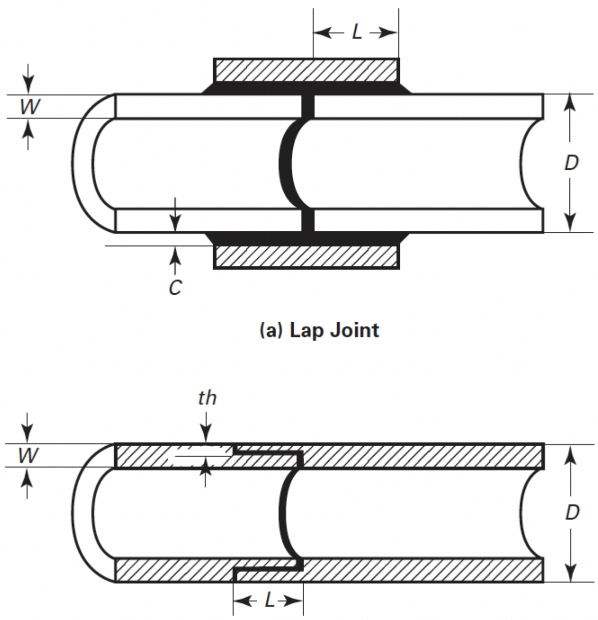
FOR PIPE BETWEEN TWO VESSELS OR OTHER MACHINERY WHERE LEGS ARE UNEQUAL; THE DIFFERENTIAL VERTICAL EXPANSION BEING COMPENSATED FOR BY MAKING THE BELLOWS UNIT LENGTH EQUAL TO THE DIFFERENCE IN THE VERTICAL LEG LENGTHS. USE DOUBLE HINGED BELLOWS.

Brazed joints

- ✓ **Brazed joints** are prohibited in piping systems with design conditions greater than Class 300. However, for other classes at industrial pipelines are acceptable if are suitable for the intended critical service of hydrogen applications.

(a) The lap joint for tubular parts requires the selection of preformed fittings, such as couplings, reducers, elbows, and flanges,

b) Butt lap joint for tubular parts requires a machining preparation to develop a socket type of connection.



(a) Lap Joint

(b) Buttlap Joint

C = joint clearance
D = diameter of lap area
F = shear strength of brazed filler metal
J = joint integrity factor of 0.8
L = length of lap area
= [*W* (*D* − *W*) *T*] / *JFD*
T = tensile strength of weakest member
th = thickness of thinner joint member
W = wall thickness of weakest member

Brazed joint considerations

- Couplings with Internal Stops All couplings (fittings) for newly constructed and repair brazements shall be manufactured with internal stops. The stops shall control the internal gap between the pipe component ends.
- Brazed joints that have been found to be defective may be rebrazed, where feasible, after thorough cleaning, by employing the same brazing procedure used for the original brazement.
- Chemical surface cleaning shall be used to remove contaminants that prohibit quality brazing. The affected surfaces shall be free from paint, oil, rust, scale, grease, slag, oxides, and other deleterious material that would be detrimental to the base metal.
- Mechanical Surface Preparation

(1) Mechanical surface preparation shall be performed by wire brushing, grinding, buffing, and polishing when required, to remove harmful defects such as fissures, pits, gouges, folds, laps, or oxides.

(2) Such methods are also used for removing objectionable surface conditions, roughening faying surfaces, and preparation.

(a) Preparation of Pipe Component Ends. Mechanical cutting and machining methods shall be applicable to the specified base material of pipe components. The methods shall be specific to the material type, such as copper, copper alloys, and austenitic stainless steels.

(b) Preparation of Joints

(1) The ends to be brazed with filler metal shall be prepared by machining or facing to provide a square end or joint detail that meets the requirements following figure from slide 28

(2) The brazed joints shall be properly cleaned, along with the areas of the inside and outside surfaces for a minimum distance of 25 mm (1 in.).

(c) Alignment for Brazing

(1) Alignment using mechanical alignment tools may be used to maintain alignment of the joint to be brazed.

(2) The joint clearance shall be maintained within the specified limits of the BPS/PQR to achieve the proper capillary action to distribute the molten filler metal between the surfaces of the base metal during the brazing operation.

(3) The specified lap of each joint type shall be fully inserted for alignment and maximum strength at the joint.

Compression joints

Compression fittings are one of the most common and versatile methods of joining small diameter metal or hard plastic tubing. Particularly useful due to their extreme temperature and pressure capabilities, and their compatibility with aggressive fluids.

Compression fittings are used in various industries, such as petrochemicals, laboratories, aerospace, shipbuilding, heavy industries etc. and they are used to make leak-free pipe connections relatively easily and quickly. Swagelok and Parker are the two leading manufacturers in the compression fittings market.

Compression fittings vary in design from manufacturer to manufacturer, but all consist of the same three basic elements: a compression nut or screw, one or more compression rings (ferrules) and a compression fitting housing.

The ferrule is the main sealing component of a compression fitting, and is manufactured in a wide range of material grades, from stainless steel to graphite.

Most commonly used ferrules, however, are made of metal. Metal ferrules are suitable for a wide temperature range, and can withstand high pressure loads, without relaxation.

One-piece vs. two-piece ferrules

Most basic compression fittings have a single ferrule. Single ferrule designs minimize the total number of components and work reliably when manufacturing softer materials (plastic or brass, for example).

With harder materials such as steel, however, torque is often transferred from the compression nut to the ferrule when the nut is tightened. The resulting rotation can cause the ferrule to compress asymmetrically or shift over time due to residual torque.

With stainless steel, rotation of the ferrule can also lead to wear and permanent leakage. Adding an additional, freely rotating rear ferrule can disconnect the nut from the front ferrule, preventing torque transfer.

Co-funded by the
Erasmus+ Programme
of the European Union

Double ferrule compression fitting:

The operating principle is as follows: the tube is inserted into the end of the fitting and the nut is tightened, forcing the ferrules into the fitting housing.

As the ferrules are pushed axially into the fitting housing, the angular shape of the housing presses the end of the ferrules radially onto the outside diameter of the tube, and a leak-free connection is guaranteed.

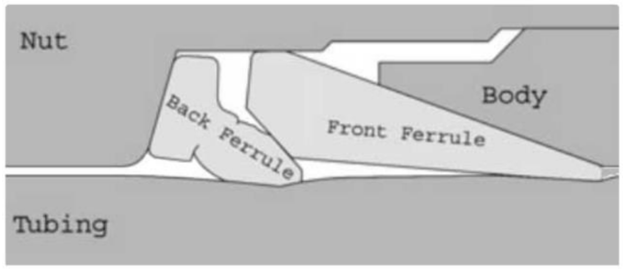


Image..swagelok.com

Other joints

Tubing Joint

Flared and flareless, tubing joints may be used. The tubing joints shall be suitable for the tubing to be used. Tubing components shall not be used beyond the pressure–temperature limits designated by the manufacturer or the applicable standards.

Caulked joints such as bell type joints shall not be used.

Soldered joints & **fillet joints** made with solder metal shall not be used.

(a) Tubing Joints Conforming to Listed Standards. Tubing joint standards listed in Table IP-8.1.1-1 are suitable for use. Designs shall be checked for adequacy of mechanical strength under applicable loadings enumerated in para. IP-2.1. (b) Tubing Joints Not Conforming to Listed Standards. The design shall be qualified as required by para. IP-3.8.2. Designs shall be checked for adequate mechanical strength under applicable loadings enumerated in para. IP-2.1. Designers shall also consider assembly and disassembly, hydrogen embrittlement, and other factors applicable to the particular application. Mating of components from different manufacturers shall be permitted only when specified in the engineering design.

Brazed joints made in accordance with the provisions in paras. GR-3.2, GR-3.8, IP-9.6.1, and IP-9.11 are suitable. They shall be safeguarded. The melting point of brazing alloys shall be considered where possible exposure to fire is involved.

Fillet joints made with brazing filler metal are not permitted.

References

- Empirical Profiling of Cold Hydrogen Plumes formed from Venting of LH2 Storage Vessels. https://www.nrel.gov/docs/fy18osti/68771.pdf
- G.R. Astbury, Venting of Low Pressure Hydrogen Gas: A Critique of the Literature, https://doi.org/10.1205/psep06054
- HYDROGEN TRANSPORTATION PIPELINES, https://h2tools.org/sites/default/files/Doc121_04%20H2TransportationPipelines.pdf
- Hydrogen Car Safety Test- Fuel Leak H2 vs. Petrol". Vimeo. Retrieved 2020-05-07.
- Explosive Lessons in Hydrogen Safety | APPEL Knowledge Services". appel.nasa.gov.
- https://www.wermac.org/
- Hydrogen Piping and Pipelines , ASME Code for Pressure Piping, B31, https://poltar.jlab.org/filedir/Procedures/ASME%20B31.12.pdf

Understand Valves and other components required for H2 piping systems

Learning Outcomes

Objectives:

- ✓ What is valve and why they are needed
- ✓ Different types of valves and their applications
- ✓ Other components and equipment used in H_2 pipeline

General understanding of valves

- Valves are mechanical devices that controls the flow and pressure within a system or process. They are essential components of a piping system that conveys liquids, gases, vapors, slurries etc..
- Different types of valves are available..gate, globe, plug, ball, butterfly, check, diaphragm, pinch, pressure relief, control valves etc. Each of these types has a number of models, each with different features and functional capabilities. Some valves are self-operated while others manually or with an actuator or pneumatic or hydraulic is operated.

Valves Functions

a) Isolation valves

Isolation valves with lock out capabilities are used to isolate portions of the pipe line in emergencies or for routine maintenance and inspection. These should be installed in an accessible location since they may need to be manually closed on an emergency basis.

For safe maintenance access it is necessary to have a means of positive isolation with a supporting lock out or tag out maintenance procedure. Typical accepted arrangements are double block and bleed valves, blind flange, double trunnion mounted ball valve equipped with a body vent or spool removal.

These are typically ball, plug, gate, or butterfly type valves.

b) **Emergency isolation valves**

Emergency Isolation Valves (EIV) are used to provide emergency blockage of the flow. They may be manual, automatic, or both. Although the number location and type of EIVs depend on the specifics of the inspection, maintenance and risk management strategies, as a minimum they shall be provided at the beginning of the pipeline and at each user.

EIV's shall be capable of being fully closed to ensure against gas leakage and in the case of automatic valves shall be designed to close on instrument air, signal, hydraulic and electrical failure. A typical arrangement would be spring return actuators which fail closed. Fail in place valves are not acceptable.

When automated, EIV's are typically ball or gate valves and are of fire safe construction. When manual valves these are typically gate valves. It is often advisable to install a means of positive isolation along with an EIV.

c) Control and pressure reducing valves and regulators

These are used for flow and pressure control functions. The use of hardened seats and plugs or other special design features should be considered when the pressure drop through the valve or regulator is greater than 10% of the upstream pressure because of the high sonic velocity of hydrogen. Erosion, abrasion, and excessive noise should be addressed in the design.

These are frequently globe valves, but notched ball valves are also used.

Regulators should not vent process gas to the ambient in an uncontrolled way. They should either vent internally or the vent should be treated.

d) Safety relief valves

The purpose of safety relief valves is to protect the system and its components from damage caused by pressures above the maximum allowable working pressure (MAWP). Pure hydrogen service does not in general require a more or less severe analysis than most other flammable gases except that special attention should be paid to the potential of hydrogen leaking through the valve when it is closed and the requirements for safe venting must be followed. The number, location, type, sizing criteria, safe venting, and inspection intervals for pressure relief devices are governed by local regulatory authority and these requirements must be strictly followed.

Typically pressure vessels, for example large filter housings, will fall under the pressure vessel regulations and the balance will fall under the piping and / or pipe line regulations.

Some of the dos and don'ts as typically practiced.

• Safety valves should be located as close as possible to the item which they protect.

• Back pressure on the safety valve discharge caused by the vent collection system shall be considered.

• Consideration shall be given to the reaction forces when a safety valve discharges.

• API RP 520, 521 [**] are often used reference documents on safety valve relief and vent system design methods.

• Although it is preferable not to, it is sometimes necessary to install block and / or by-pass valves together with safety relief valves to meet local inspection/testing regulations or when connecting to an existing vent or flare system. However, this presents inherent safety risks since the safety valve could be blocked. Therefore, a careful analysis of the entire system, its components, and the supporting operational and maintenance procedures (e.g. lock out) by an experienced professional shall be performed.

e) Manual vent and drain valves

Typical practice is to provide positive sealing through the valve by redundancy. The most common arrangements used are double valves, blind flange, plug, or cap (plugs and caps should be threaded without seal welding since it is necessary to remove them for the vent valve to perform its function).

These are typically ball, plug, gate, or globe valves.

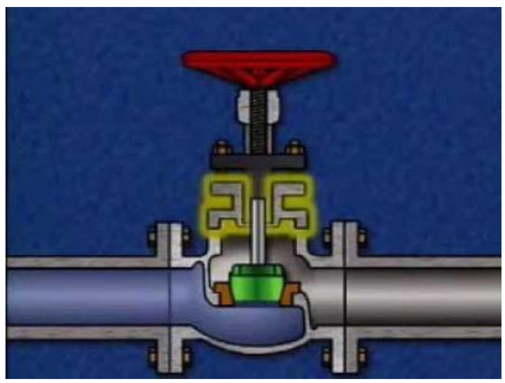
f) Excess flow valves (EFV)

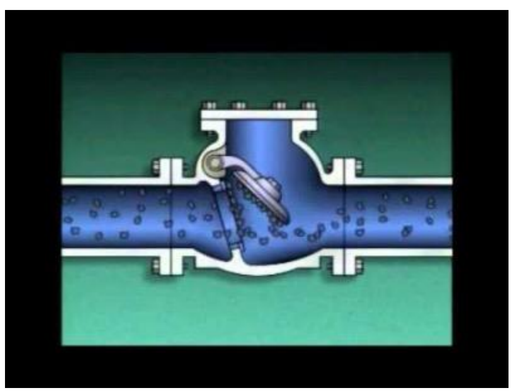
EFV valves are usually designed similarly to emergency isolation valves (EIV').

g) Check valves (non-return valves)

Pure hydrogen does not present special concerns for check valves besides leakage. The concerns are similar to those for automatic valves and a soft seat in a metal retainer or specially lapped metal to metal seats are preferred, especially when small back leakage would present a significant risk. As with all check valves installation in the proper orientation can be crucial. Typically check valves are not considered fully reliable flow stoppers. Therefore, a check valves shall not be used as a substitute for an isolation valve.

Valve types and operations





Co-funded by the
Erasmus+ Programme
of the European Union

Valve parts

a) Valve body

The valve body, sometimes called the shell, is the primary boundary of a pressure valve. He serves as the main element of a valve assembly because it is the framework that holds all the parts together.

The body, the first pressure boundary of a valve, resists fluid pressure loads from connecting piping. It receives inlet and outlet piping through threaded, bolted, or welded joints.

The valve-body ends are designed to connect the valve to the piping or equipment nozzle by different types of end connections, such as butt or socket welded, threaded or flanged.

Valve bodies are cast or forged in a variety of forms and each component have a specific function and constructed in a material suitable for that function.

Valve Body

b) Valve bonnet

The cover for the opening in the body is the bonnet, and it is the second most important boundary of a pressure valve. Like valve bodies, bonnets are in many designs and models available.

Co-funded by the
Erasmus+ Programme
of the European Union

A bonnet acts as a cover on the valve body, is cast or forged of the same material as the body. It is commonly connected to the body by a threaded, bolted, or welded joint. During manufacture of the valve, the internal components, such as stem, disk etc., are put into the body and then the bonnet is attached to hold all parts together inside.

In all cases, the attachment of the bonnet to the body is considered a pressure boundary. This means that the weld joint or bolts that connect the bonnet to the body are pressure-retaining parts. Valve bonnets, although a necessity for most valves, represent a cause for concern. Bonnets can complicate the manufacture of valves, increase valve size, represent a significant cost portion of valve cost, and are a source for potential leakage.

c) Valve Trim

The removable and replaceable valve internal parts that come in contact with the flow medium are collectively termed as Valve trim. These parts include valve seat(s), disc, glands, spacers, guides, bushings, and internal springs. The valve body, bonnet, packing, et cetera that also come in contact with the flow medium are not considered valve trim.

A Valve's trim performance is determined by the disk and seat interface and the relation of the disk position to the seat. Because of the trim, basic motions and flow control are possible. In rotational motion trim designs, the disk slides closely past the seat to produce a change in flow opening. In linear motion trim designs, the disk lifts perpendicularly away from the seat so that an annular orifice appears.

Valve trim parts may be constructed of assorted materials because of the different properties needed to withstand different forces and conditions. Bushings and packing glands do not experience the same forces and conditions as do the valve disc and seat(s).

Flow-medium properties, chemical composition, pressure, temperature, flow rate, velocity and viscosity are some of the important considerations in selecting suitable trim materials. Trim materials may or may not be the same material as the valve body or bonnet.

d) Valve Disk and Seat(s)

Disc The disc is the part which allows, throttles, or stops flow, depending on its position. In the case of a plug or a ball valve, the disc is called plug or a ball. The disk is the third most important primary pressure boundary. With the valve closed, full system pressure is applied across the disk, and for this reason, the disk is a pressure related component. Disks are usually forged, and in some designs, hard surfaced to provide good wear properties. Most valves are named, the design of their disks.

Seat(s) The seat or seal rings provide the seating surface for the disk. A valve may have one or more seats. In the case of a globe or a swing-check valve, there is usually one seat, which forms a seal with the disc to stop the flow. In the case of a gate valve, there are two seats; one on the upstream side and the other on the downstream side. A gate valve disc has two seating surfaces that come in contact with the valve seats to form a seal for stopping the flow. To improve the wear-resistance of the seal rings, the surface is often hard-faced by welding and then machining the contact surface of the seal ring. A fine surface finish of the seating area is necessary for good sealing when the valve is closed. Seal rings are not usually considered pressure boundary parts because the body has sufficient wall thickness to withstand design pressure without relying upon the thickness of the seal rings.

e) Valve Stem

The valve stem provides the necessary movement to the disc, plug or the ball for opening or closing the valve, and is responsible for the proper positioning of the disk. It is connected to the valve handwheel, actuator, or the lever at one end and on the other side to the valve disc. In gate or globe valves, linear motion of the disc is needed to open or close the valve, while in plug, ball and Butterfly valves, the disc is rotated to open or close the valve.

Stems are usually forged and connected to the disk by threaded or other techniques. To prevent leakage, in the area of the seal, a fine surface finish of the stem is necessary.

There are five types of valve stems:

Rising Stem with Outside Screw and Yoke

The exterior of the stem is threaded, while the portion of the stem in the valve is smooth. The stem threads are isolated from the flow medium by the stem packing. Two different styles of these designs are available; one with the handwheel attached to the stem, so they can rise together, and the other with a threaded sleeve that causes the stem to rise through the handwheel. This type of valve is indicated by "O. S. and Y." is a common design for NPS 2 and larger valves.

Rising Stem with Inside Screw

The threaded part of the stem is inside the valve body, and the stem packing along the smooth section that is exposed to the atmosphere outside. In this case, the stem threads are in contact with the flow medium. When rotated, the stem and the handwheel to rise together to open the valve.

Non Rising Stem with Inside Screw

The threaded part of the stem is inside the valve and does not rise. The valve disc travels along the stem, like a nut if the stem is rotated. Stem threads are exposed to the flow medium, and as such, are subjected to the impact. That is why this model is used when space is limited to allow linear movement, and the flow medium does not cause erosion, corrosion or abrasion of the stem material.

Sliding Stem

This valve stem does not rotate or turn. It slides in and out the valve to open or close the valve. This design is used in hand-operated lever rapid opening valves. It is also used in control valves are operated by hydraulic or pneumatic cylinders.

Rotary Stem

This is a commonly used model in ball, plug, and Butterfly valves. A quarter-turn motion of the stem open or close the valve.

f) Valve Yoke and Yoke Nut

Yoke

A Yoke connects the valve body or bonnet with the actuating mechanism. The top of the Yoke holding a Yoke nut, stem nut, or Yoke bushing and the valve stem passes through it. A Yoke usually has openings to allow access to the stuffing box, actuator links, etc.. Structurally, a Yoke must be strong enough to withstand forces, moments, and torque developed by the actuator.

Yoke Nut

A Yoke nut is an internally threaded nut and is placed in the top of a Yoke by which the stem passes. In a Gate valve e.g., the Yoke nut is turned and the stem travels up or down. In the case of Globe valves, the nut is fixed and the stem is rotated through it.

Valve Stem Packing

For a reliable seal between the stem and the bonnet, a gasket is needed. This is called a Packing, and it is fitted with e.g. the following components..

- Gland follower, a sleeve which compresses the packing, by a gland into the so called stuffing box.
- Gland, a kind of bushing, which compressed de packing into the stuffing box.
- Stuffing box, a chamber in which the packing is compressed.
- Packing, available in several materials, like Teflon®, elastomeric material, fibrous material etc..
- A backseat is a seating arrangement inside the bonnet. It provides a seal between the stem and bonnet and prevents system pressure from building against the valve packing, when the valve is fully open. Back seats are often applied in gate and globe valves.

An important aspect of the life time of a valve is the sealing assembly. Almost all valves, like standard Ball, Globe, Gate, Plug and Butterfly valves have their sealing assembly based upon shear force, friction and tearing.

Therefore valve packaging must be properly happen, to prevent damage to the stem and fluid or gas loss. When a packing is too loose, the valve will leak. If the packing is too tight, it will affect the movement and possible damage to the stem.

Valve Actuators

Hand-operated valves are usually equipped with a handwheel attached to the valve's stem or Yoke nut which is rotated clockwise or counter clockwise to close or open a valve. Globe and gate valves are opened and closed in this way.

Hand-operated, quarter turn valves, such as Ball, Plug or Butterfly, has a lever for actuate the valve.

There are applications where it is not possible or desirable, to actuate the valve manually by handwheel or lever. These applications include:

- Large valves that must be operated against high hydrostatic pressure
- Valves they must be operated from a remote location
- When the time for opening, closing, throttle or manually controlling the valve is longer, than required by system-design criteria

These valves are usually equipped with an actuator. An actuator in the broadest definition is a device that produces linear and rotary motion of a source of power under the action of a source of control.

Basic actuators are used to fully open or fully close a valve. Actuators for controlling or regulating valves are given a positioning signal to move to any intermediate position. There a many different types of actuators, but the following are some of the commonly used valve actuators.

- Gear Actuators
- Electric Motor Actuators
- Pneumatic Actuators
- Hydraulic Actuators
- Solenoid Actuators

Hand-operated valves are usually equipped with a handwheel attached to the valve's stem or Yoke nut which is rotated clockwise or counter clockwise to close or open a valve. Globe and gate valves are opened and closed in this way.

Hand-operated, quarter turn valves, such as Ball, Plug or Butterfly, has a lever for actuate the valve.

There are applications where it is not possible or desirable, to actuate the valve manually by handwheel or lever. These applications include:

- Large valves that must be operated against high hydrostatic pressure
- Valves they must be operated from a remote location
- When the time for opening, closing, throttle or manually controlling the valve is longer, than required by system-design criteria

These valves are usually equipped with an actuator. An actuator in the broadest definition is a device that produces linear and rotary motion of a source of power under the action of a source of control.

Basic actuators are used to fully open or fully close a valve. Actuators for controlling or regulating valves are given a positioning signal to move to any intermediate position. There a many different types of actuators, but the following are some of the commonly used valve actuators.

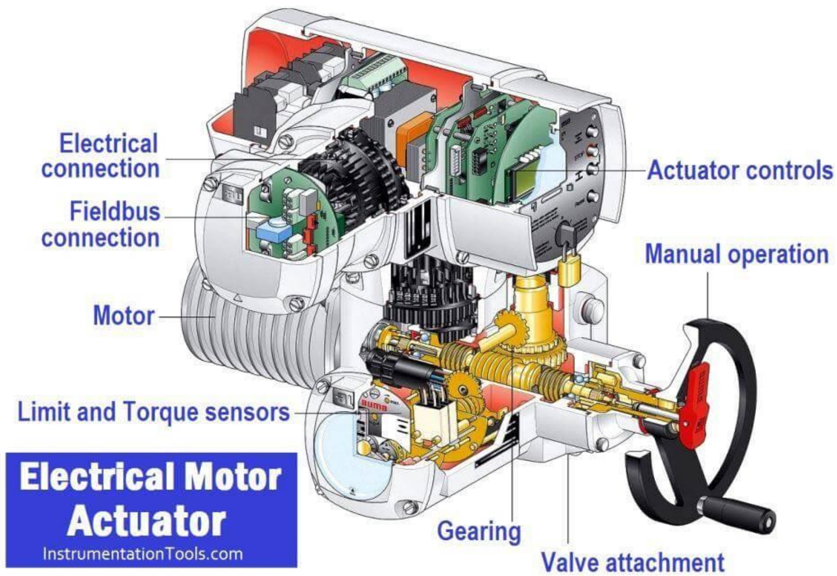
- Gear actuators are the most common type of valve actuators. Manual actuators include handwheels attached to the valve stem directly and handwheels attached through gears to provide a mechanical advantage.
- Electric motor actuators consist of reversible electric motors connected to the valve stem through a gear train that reduces rotational speed and increases torque.
- Pneumatic actuators use air pressure on either one or both sides of a diaphragm to provide the force to position the valve.
- Hydraulic actuators use a pressurized liquid on one or both sides of a piston to provide the force required to position the valve.

Co-funded by the
Erasmus+ Programme
of the European Union

- Solenoid actuators have a magnetic slug attached to the valve stem. The force to position the valve comes from the magnetic attraction between the slug on the valve stem and the coil of the electromagnet in the valve actuator.

Electric motor actuator

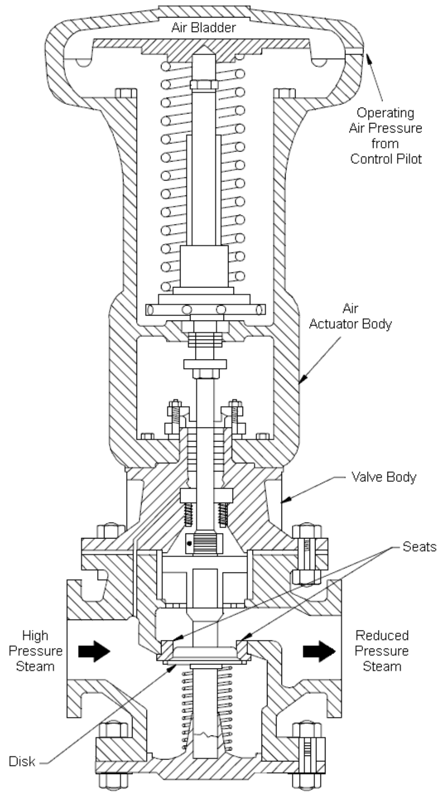
Electric motors permit manual, semi-automatic, and automatic operation of the valve. Motors are used mostly for open-close functions, although they are adaptable to positioning the valve to any point opening as illustrated in the image below. The motor is usually a, reversible, high speed type connected through a gear train to reduce the motor speed and thereby increase the torque at the stem. Direction of motor rotation determines direction of disk motion. The electrical actuation can be semi-automatic, as when the motor is started by a control system. A handwheel, which can be engaged to the gear train, provides for manual operating of the valve. Limit switches are normally provided to stop the motor automatically at full open and full closed valve positions. Limit switches are operated either physically by position of the valve or torsionally by torque of the motor.



Pneumatic Actuators

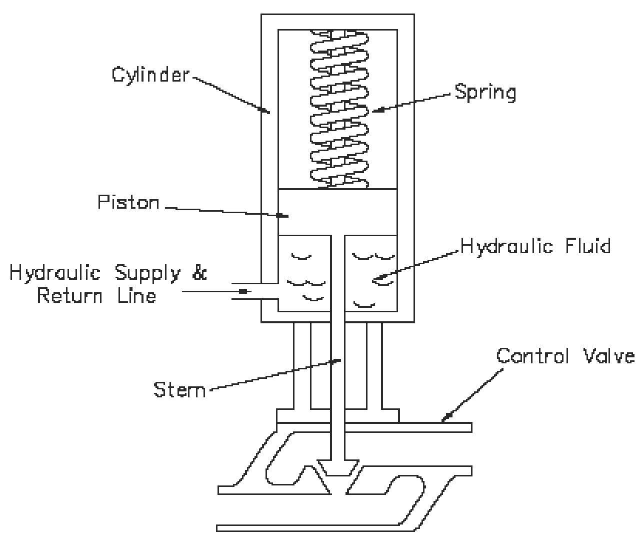
Pneumatic actuators as illustrated in the image below provide for automatic or semiautomatic valve operation. These actuators translate an air signal into valve stem motion by air pressure acting on a diaphragm or piston connected to the stem. Pneumatic actuators are used in throttle valves for open-close positioning where fast action is required. When air pressure closes the valve and spring action opens the valve, the actuator is termed direct acting. When air pressure opens the valve and spring action closes the valve, the actuator is termed reverse acting. Duplex actuators have air supplied to both sides of the diaphragm. The differential pressure across the diaphragm positions the valve stem. Automatic operation is provided when the air signals are automatically controlled by circuitry. Semi-automatic operation is provided by manual switches in the circuitry to the air control valves.

Co-funded by the
Erasmus+ Programme
of the European Union



Hydraulic Actuators

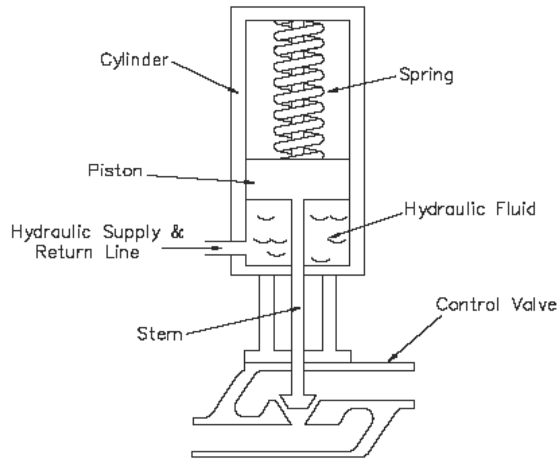
Hydraulic actuators provide for semi-automatic or automatic positioning of the valve, similar to the pneumatic actuators. These actuators use a piston to convert a signal pressure into valve stem motion. Hydraulic fluids fed to either side of the piston while the other side is drained or bled. Water or oil is used as the hydraulic fluid. Solenoid valves are typically used for automatic control of the hydraulic fluid to direct either opening or closing of the valve. Manual valves can also be used for controlling the hydraulic fluid; thus providing semi-automatic operation.



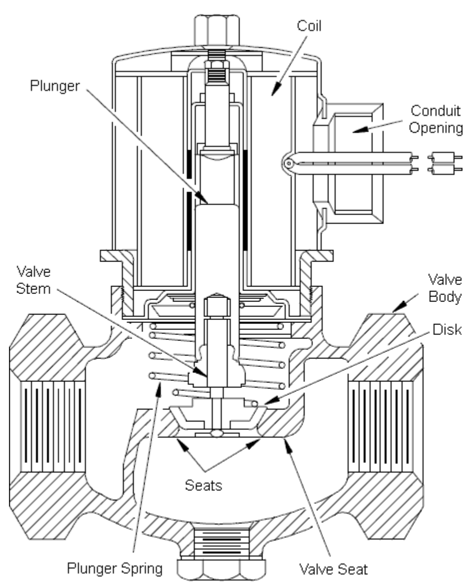
Co-funded by the Erasmus+ Programme of the European Union

Self-Actuated Valves

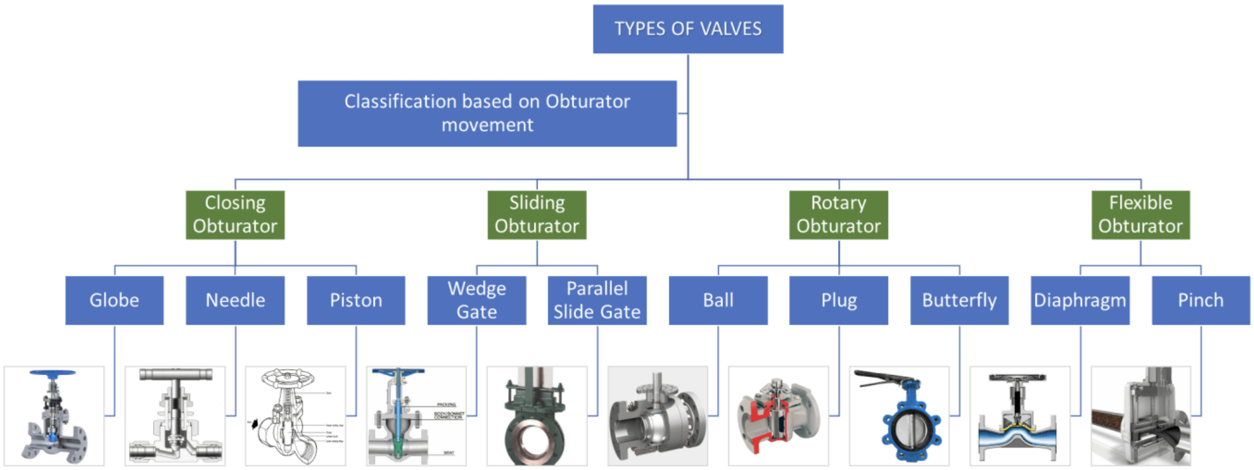
Self-actuated valves use the system fluid to position the valve. Relief valves, safety valves, check valves, and steam traps are examples of self-actuated valves. All of these valves use some characteristic of the system fluid to actuate the valve. No source of power outside the system fluid energy is necessary for operation of these valves.



Solenoid actuated valves provide for automatic open-close valve positioning as illustrated in the image below. Most solenoid actuated valves also have a manual override that permits manual positioning of the valve for as long as the override is manually positioned. Solenoids position the valve by attracting a magnetic slug attached to the valve stem. In single solenoid valves, spring pressure acts against the motion of the slug when power is applied to the solenoid. These valves can be arranged such that power to the solenoid either opens or closes the valve. When power to the solenoid is removed, the spring returns the valve to the opposite position. Two solenoids can be used to provide for both opening and closing by applying power to the appropriate solenoid.



Classification of Valves based on Closure Element



Closing Obturator: In this type of valve the closure member i.e. disc or plug moves along the seat axis, towards or away from the direction of valve seat or port. Globe valve, Needle valve and Piston valve fall in this category of valves.

Sliding Obturator: In this type of valve, the closure member i.e. wedge gate or parallel gate moves perpendicular to the direction of flow at the valve port. Gate valves fall in this category of valves. Ball valves, Plug valves and Butterfly valves fall in this category of valves.

Rotary Obturator: In this type of valve, the closure member has a port which is turned through 90 degrees such that the port aligns with the direction of flow allowing full flow across the valve or the port is at right angles to the direction of flow shutting off the flow.

Flexible Obturator: In this type of valve, the closure member is a flexible passage which is flattened or pinched to restrict the flow and vice versa to let flow pass through the valve. Diaphragm valves and Pinch valves fall in this category of valves.

Valve in H_2 pipelines

The major concern specific to pure hydrogen service is to prevent leakage either to the ambient or across the valve.

Leakage to ambient is most frequently caused by packing and bonnet leaks and to a lesser extent by leaking castings.

To minimize the potential for leaks …

• Double seals or packing

• Each casting to be hydraulically leak tested

• Soft seat in a metal retainer for in-line automatic valves and automatic vents; specify bubble tight shut off

• Metal to metal seat or soft seat in a retainer for in-line manual valves; these should be combined with a means of positive isolation if used to block flow before attempting maintenance or inspection inside the line.

• Metallic seat with valve outlet blocked. Typical arrangements used are double valves, blind flange, plug, or cap (threaded connections are acceptable).

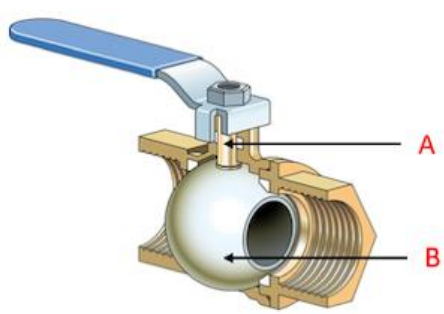
• Preferably no through bolting, body flanges or threaded connections in assembly of the body of the valve.

• Mainline isolation valves should be of full port design, when pipeline pigging for inspection is foreseen

Popular types of valves used in H_2 pipelines

Ball and plug valves are inherently quick opening and good sealing. They can be manually or automatically operated. They are frequently preferred as isolation, emergency isolation, excess flow, and vent and drain valves. They can also be used as control valves in certain circumstances although their control characteristics are generally less precise than globe valves or butterfly valves. Ball valves are usually full ported and must be full ported if it is required to run a pipeline internal inspection device through them. Ball and plug valves are typically used in small sizes.

a)plug valve

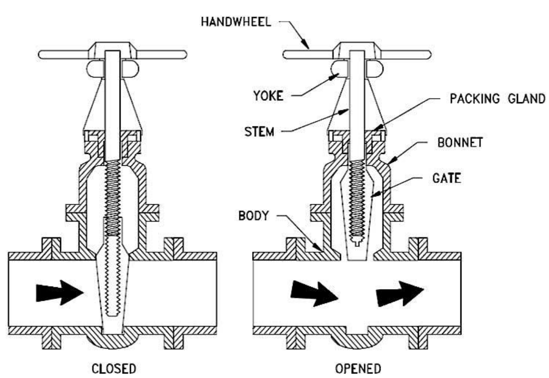


b)ball valve

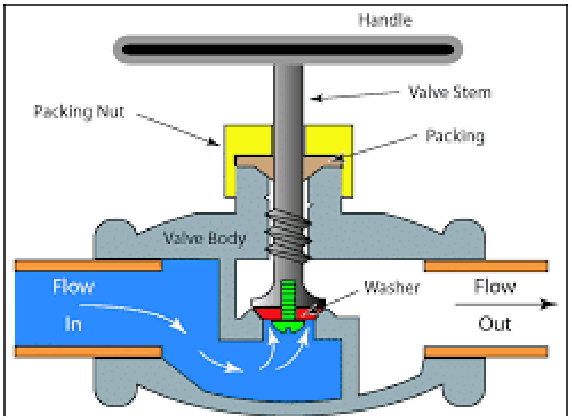
Eccentric disc wafer valves (high performance butterfly) may be used. They can be manually or automatically operated and can be used as a control valve when the pressure drop across the valve is not too large. The main disadvantage is that the valve seat is particularly exposed to particulate damage. If these are chosen, they shall be double eccentric and bubble tight shut off. Butterfly valves are not suitable to run a pipeline internal inspection device through since the disc and pin sit permanently in the flow path.

This document does not take a position on the use of these valves other than to acknowledge that there is difference of opinion about their use with some pipe line operators allowing them in certain circumstances and others not permitting them at all. However, as there are potential benefits in certain situations, a description of them was considered appropriate to include.

Gate valves are rugged proven valves which are typically used to block flows. Although they can be automated they are by far most often manually operated. The main disadvantage is that, except for certain special designs with soft sealing strips on the disc, they are not as tight sealing as ball, plug, butterfly, or globe valves. To mitigate this they should be specified with flexible wedges (gates). Gate valves are suitable to run a pipeline internal inspection device through them.



Globe valves are commonly used in control applications and where a tight shut off is a pre-eminent concern. They can be manually or automatically operated. They are widely used as control valves because of the precise nature of their control characteristics. They are also used as automated vent and isolation valves because of their tight shut off. They are more used at smaller sizes than larger sizes. The gas which flows through a globe valve is forced to change direction. This is how its precise control characteristic is created, however, it makes them susceptible to erosion and abrasion. For this reason the use of hardened plug and seat materials should be considered in applications which have a large pressure drop across the valve. The high sonic velocity of hydrogen means that this problem occurs at lower pressure drops than with most other gases.



These are valves which are specifically designed to prevent over pressurization of an item or system by automatically and reliably stopping the increase of internal pressure by venting gas once a pre set pressure has been reached. Pressure relief valves are self contained in that they do not require operator or control system actuation to perform their function. There are several different types and styles of safety relief valves including direct acting, pilot operated, variable back pressure, etc. Direct acting spring actuated relief valves are acceptable. Internals should be of hydrogen compatible corrosion resistant materials. Both metal to metal and soft materials in a metal retainer are typically used as seats. The main difference between them is that metal to metal seats are less likely to be damaged when the safety valve lifts but they also tend to leak more easily when the safety valve is closed.

Pressure relief valves typically must meet international, national, and local regulatory requirements which typically include design, materials of construction, testing, quality assurance, inspection in service, and often official sealing after the relief pressure has been set to guard against tampering.

Although many materials may be used for the valve body, it is preferable to use either carbon steel or stainless steel since these materials are economic and avoid some of the potential corrosion issues which could arise if impurities entered the pipe line.

Example of available H_2 pressure relief valves in the market:

Co-funded by the
Erasmus+ Programme
of the European Union

Cryogenic Hydrogen Pressure Relief Valve – Series 2400

Hydrogen Pressure Relief Valve – Series 451

These are valves which are specifically designed to permit flow in one direction and to stop it in the reverse direction. There are numerous types including swing, flapper, ball, poppet, spring loaded, gravity operated, hydraulic assisted, etc. Swing and flapper types are most often used in larger sizes and ball or poppets in very small sizes (<2”). To minimize back leakage when the valve is closed, a soft seat in a metal retainer or specially lapped metal to metal seats are preferred, especially when a small backwards flow would present a significant risk. As with all check valves installation in the proper orientation can be crucial. Typically check valves are not considered as reliable flow stoppers as isolation valves and, therefore, a check valves shall not be used a substitute for an isolation valve.

Cryogenic Lift Check Valves for Hydrogen Application

Valve issues in H_2 pipelines

Packing

Positive sealing of packing glands is important in hydrogen service. Packing materials should be hydrogen compatible and suitable for high temperatures to better maintain their integrity in case of a fire. Graphite based compounds are typically used. Double packing should be used to mitigate the chance of leakage to atmosphere which can present a flammability risk.

Damage from particulates

To protect soft seats from possible damage from particulates carried with the gas, a strainer of 300 microns (50 mesh) or finer may be installed upstream of valves or valve clusters with soft seats which are normally open to flow during operation. Typically this excludes vents, drains, and pressure relief valves (pressure relief valves should not have a strainer upstream of them in any case since a partially blocked strainer would reduce the relieving capacity).

Valve production for hydrogen service

In addition to careful selection of suitable materials, it is important to ensure that further processing of these materials does not compromise their integrity. For example, the welding process can produce notches and residual stresses from local plasticization, which may then promote hydrogen embrittlement. Follow-up treatment according to NACE is recommended in these cases.

Other equipment used in H_2 piping

Strainer and filter installation is recommended to avoid contamination, particularly upstream of pressure control and metering devices, as the sonic velocity of hydrogen is very high compared with most gases The housing material should as a minimum be equivalent to the pipe and the internals should be of a corrosion resistant metal.

Difference between Strainers and filters

The purpose of a strainer is to remove larger, unwanted suspended particles from a liquid, primarily to protect downstream equipment, like pumps, from damage. They come in a variety of shapes and sizes, depending on the application, but one feature is essential – strainers are designed for easy removal and cleaning. Quick cleaning requires less downtime for the equipment to ensure optimal functionality.

While strainers are used to remove larger particles, filters are used to remove smaller unwanted particles from both liquids and gasses. Filters are typically used when the liquid or gas passing through the system must be free of most contaminants, even those as small as a grain of sand. Many filters are reusable, while others must be replaced periodically.

BASIS OF DIFFERENCE	STRAINER	FILTER
FUNCTIONALITY	It traps debris and allows the valuable liquid to flow through the system.	It traps the valuable substance and lets the waste flow through the system.
NUMBER OF SCREENS	It incorporates various screens.	It incorporates a single screen.
RE-USAGE	The screens can be cleaned and used again.	The screen can be used until it is clogged, which must then be changed.
TYPE OF OPERATION	It is considered a coarse operation.	It is referred to as a more delicate removal process.
BASIC USAGE	It is employed to catch large chunks in the valve industry.	It is used to remove small particles down to the size of microbes.
PRESSURE DROP	Liquid or gas passing through a strainer does not experience a pressure drop.	Liquid or gas passing through a filter experience a pressure drop.
SIZE OF PARTICLES	A strainer is used to remove particles larger than 40 microns.	A filter is used to remove particles smaller than 40 microns.
QUICK CLEANING	Quick cleaning of a strainer requires less downtime.	Quickly cleaning a filer is impossible as it consumes a considerable amount of time.

Co-funded by the
Erasmus+ Programme
of the European Union

Flow measuring devices

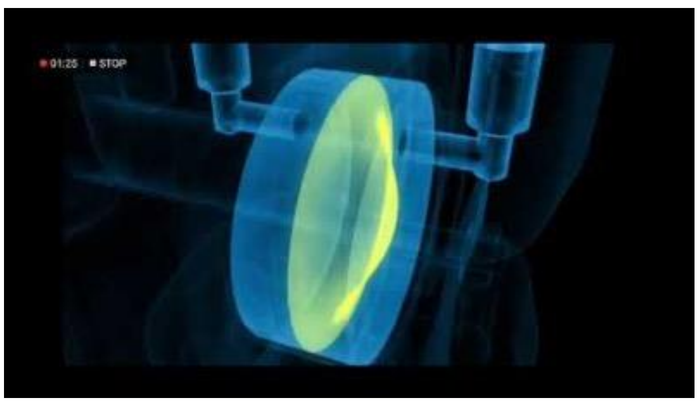
Orifice plate, venturi and turbine meters are frequently used.

The selection of flow meter type is normally based on the accuracy requirements for the required range of gas flow to meet customer requirements. Instrumentation for converting the output from the volumetric primary device into a mass flow may use an Integrated Electronic System, which may comprise the following:

- pressure transmitter
- temperature transmitter
- differential pressure transmitter
- mass flow computer

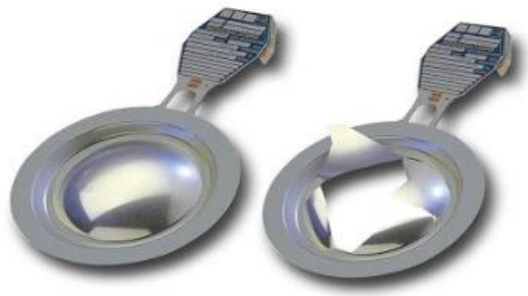
Working principle of orifice plate

It works on the Differential Pressure Measurement principle. The liquid or gas whose flow rate is to be determined is passed through the orifice plate. This creates a pressure drop across the orifice plate which varies with the flow rate, resulting in a differential pressure between the outlet and inlet segments.



Rupture discs

Safety relief valves are preferred to rupture discs because rupture discs are more prone to premature failure and once actuated they are not self-closing. Overall this means that it is more likely to have an accidental release of hydrogen and that the release will be large and will continue until the source of hydrogen is blocked. Therefore, rupture discs shall not be used unless a safety valve is not practical. In case a rupture disc is unavoidable, the requirements generally follow those for safety relief valves. Rupture discs must be compatible with hydrogen and resistant to atmospheric corrosion.



Insulating joints

Insulating joints are essentially two pieces of pipe separated by a material with a high dielectric constant (insulator) so as to electrically isolate two systems or items. Typically this is done to create separate zones of possible corrosion for example between underground and aboveground segments of the pipe line. Although the design of these devices is well known, there is still a possibility that a spark may be created between the electrically isolated sections and that this spark might ignite a fire.

Proper specification and installation of insulating joints is necessary to mitigate this risk. Therefore, a knowledgeable and experienced person should review the specification and installation of this item.

Flexible connections

When piping and equipment warms up it expands putting stress on the system as it changes shape to accommodate the now longer material. A flexible connection is a device to allow for this growth by its inherent flexibility; it expands so the piping does not have to. Unfortunately, flexible connections are significantly less robust in service as pipe, and this presents a significantly increased risk of failure, which would be dangerous with any flammable gas, and even more with hydrogen. The preferred solution is to design flexibility into the piping system by means of expansion loops (out of plane runs of pipe) and this shall be the design used unless there is no practical alternative.

In case a flexible connection is unavoidable it shall be made of corrosion resistant metal, have a liner, and shall be inspected frequently in service to detect early signs of incipient failure. Expansion joints may be in accordance with existing standards, such as of the Expansion Joint Manufacturer's Association (EJMA).

Proper specification and installation of flexible connections is necessary or they may fail prematurely or even immediately. Therefore, a knowledgeable and experienced person should review the specification and installation of this item.

Summary of requirements and standards for valves

(a) Valves shall conform to standards and specifications referenced in this Code and shall be used only in accordance with the service recommendations of the manufacturer.

(1) Valves manufactured in accordance with the following standards may be used:

(a) ASME B16.34

(b) ASME B16.38

(c) API 6D

(d) API 609

(e) API 600

(f) API 602

(2) Valves having shell (body, bonnet, cover, and/or end flange) components made of cast or ductile iron shall not be used in hydrogen service.

(3) Pipeline valves purchased to API 6D requirements shall be capable of passing the pressure tests described in API 6D Annex C, para. C4, using helium as the test medium. Other valves shall be capable of passing the pressure tests described in API 598, using helium as the test medium.

(b) Threaded valves shall be threaded according to ASME B1.20.1 or API 5B.

(c) Pressure reducing devices shall conform to the requirements of this Code for valves in comparable service conditions.

Consideration for H_2 valves

- 300 series austenitic stainless steels that meet the temperature limits of ASME B31.12 are used for liquid and gaseous hydrogen product piping, tubing, valves, and fittings.
- Where the study required in para. PL-3.6.1 indicates that the Location Class has changed, the sectionalizing valve locations shall be reviewed to determine if access to the valves has been affected. Access routes to the valves shall be evaluated. The effects of evacuating the pipeline in the vicinity of the valves shall be determined. New routes and evacuation and valve location plans shall be developed as required.

Main requirements for Design of Pressure-Relief and Pressure-Limiting Installations

a)Pressure-relief or pressure-limiting devices except rupture disks shall:

(1) be constructed of materials such that the operation of the device will not normally be impaired by corrosion of external parts by the atmosphere or internal parts by gas

(2) have valves and valve seats that are designed not to stick in a position that will make the device inoperative and result in failure of the device to perform in the manner for which it was intended

(3) be designed and installed so that they can be readily operated to determine if the valve is free, can be tested to determine the pressure at which they will operate, and can be tested for leakage when in the closed position

(b) Rupture discs shall meet the requirements for design as set out in the ASME BPV Code, Section VIII, Division 1.

(c) The discharge stacks, vents, or outlet ports of all pressure relief devices shall be located where gas can be discharged into the atmosphere without undue hazard.

As it is likely that hydrogen will ignite spontaneously when released, consideration should be given to all exposures in the immediate vicinity when deciding on the location of a vent to atmosphere. API 521 should be used to determine a safe setback distance from hydrogen vents. The possibility of ignition may be reduced by injecting an inert gas into the vent stack. Where required to protect devices, the discharge stacks or vents

(d) The size of the openings, pipe, and fittings located between the system to be protected and the pressure relieving device and the vent line shall be of adequate size to prevent hammering of the valve and to prevent impairment of relief capacity.

(e) Precautions shall be taken to prevent unauthorized operation of any stop valve that will make a pressure relief valve inoperative. This provision shall not apply to valves that will isolate the system under protection from its source of pressure. Acceptable methods for complying with this provision are as follows:

(1) Lock the stop valve in the open position. Instruct authorized personnel of the importance of not inadvertently leaving the stop valve closed and of being present during the entire period that the stop valve is closed so that they can lock it in the open position before they leave the location.

(2) Install duplicate relief valves, each having adequate capacity by itself to protect the system, and arrange the isolating valves or three-way valve so that mechanically it is possible to render only one safety device inoperative at a time.

Required spacing of valves

(a) Sectionalizing valves shall be installed in new transmission pipelines at the time of construction. When determining the sectionalizing valve spacing, primary consideration shall be given to locations that provide continuous accessibility to the valves. Other factors involve the conservation of gas, time to blow down the isolated section, continuity of gas service, necessary operating flexibility, expected future development within the valve spacing section, and significant natural conditions that may adversely affect the operation and security of the line.

(b) Notwithstanding the considerations in (a) above, the spacing between valves on a new transmission line shall not exceed the following:

(1) 20 mi in areas of predominantly Location Class 1

(2) 15 mi in areas of predominantly Location Class 2

(3) 10 mi in areas of predominantly Location Class 3

(4) 5 mi in areas of predominantly Location Class 4

(c) The spacing defined in (b) above may be adjusted slightly to permit a valve to be installed in a more accessible location, with continuous accessibility being the primary consideration.

(d) No valves shall be installed in a confined space or in a vault unless adequate ventilation is provided.

References

- Empirical Profiling of Cold Hydrogen Plumes formed from Venting of LH2 Storage Vessels. https://www.nrel.gov/docs/fy18osti/68771.pdf
- https://www.api.org/~/media/files/publications/whats%20new/521%20e6%20pa.pdf
- G.R. Astbury, Venting of Low Pressure Hydrogen Gas: A Critique of the Literature, https://doi.org/10.1205/psep06054
- HYDROGEN TRANSPORTATION PIPELINES, https://h2tools.org/sites/default/files/Doc121_04%20H2TransportationPipelines.pdf
- Hydrogen Car Safety Test- Fuel Leak H2 vs. Petrol". Vimeo. Retrieved 2020-05-07.
- Explosive Lessons in Hydrogen Safety | APPEL Knowledge Services". appel.nasa.gov.
- https://www.wermac.org/
- Hydrogen Piping and Pipelines , ASME Code for Pressure Piping, B31, https://poltar.jlab.org/filedir/Procedures/ASME%20B31.12.pdf

Co-funded by the Erasmus+ Programme of the European Union

Understand Hydrogen installations techniques, choice of material and tubing codes

Learning Outcome 3

General Considerations for safe operation of high pressure H2 pipeline

- ✓ LH2 containers, static and mobile, and associated piping shall be electrically bonded and grounded
- ✓ All off-loading facilities shall provide easily accessible grounding connections and be located outside the immediate transfer area. Facility grounding connections should be less than 10 W resistance. Transfer subsystem components should be grounded before subsystems are connected.
- ✓ The roadways and area surfaces located below LH2 piping from which liquid air may drop shall be constructed of non-combustible materials such as concrete. Asphalt shall not be used.
- ✓ Piping carrying hydrogen to the use point from the dewars, trailers, and storage vessels shall be installed above ground. Lines crossing roadways should be installed in concrete channels covered with an open grating. Hydrogen transmission lines shall not be located beneath electric power lines.
- ✓ LH2 vessels should be designed to include thermal protection systems to minimize the evaporation losses. The types of insulation systems employed are the following:

(a) A vacuum equal to that required under operating conditions

(b) High vacuum plus powders such as perlite, silica aerogel, diatomaceous earth, fused alumina, and phenolic spheres

(c) Multiple layers of highly reflecting radiation shields separated by spacers or insulators plus a high vacuum

(d) Materials with low thermal conductivity (Hastelloy" , titanium) used to support the insulation

- ✓ The inner vessel should be designed to have a vapor tight seal in the outer jacket or covering to prevent air condensation and oxygen enrichment within the insulation. Condensed air in the insulation systems may explosively expand as it reverts to a gas when the LH2 is emptied from the tanks or pipes.
- ✓ Construction materials for surfaces exposed to a cryogen should retain the necessary mechanical properties and not tend toward low-temperature embrittlement.
- ✓ Pressure relief is required for the inner vessel and vacuum jacket.

The design of a piping system for hydrogen use shall consider the pressure, temperature, and various forces applicable to the design of a hydrogen piping system. Special consideration shall be given for the unique properties of hydrogen, such as hydrogen embrittlement. Piping systems for hydrogen use shall be designed based on the most severe condition of coincident pressure, temperature, and loading. The most severe condition shall be the one that results in the greatest required pipe thickness and highest flange rating. Piping as used in this guideline includes pipe, tubing, flanges, bolting, gaskets, valves, relief devices, fittings, and the pressure containing portions of other piping components. It also includes hangers and supports and other equipment items necessary to prevent overstressing pressure containing components.

- Most LH_2 or SLH_2 (subcooled liquid hydrogen, pressure is approximately 1.3 MPa) lines are vacuum jacketed or insulated to reduce heat input and prevent the condensation of atmospheric air. The piping vacuum jacket systems should be separate from the vacuum systems of the main hydrogen storage and handling systems. The jacket design should consider the thermal flexibility of the inner line and allow the jacket to follow its natural thermal displacement. The vacuum jacket shall have its own separate pressure-relief system
- An LH2 or SLH2 system built of stainless steel has a thermal contraction of about 0.3 percent from ambient temperature to 20 K (-423 °F). Long runs of piping require a support at intervals to allow for axial motion with lateral and vertical motion restrained.
- Insulation for LH2 or SLH2 piping shall have a self-extinguishing fire rating. Other fluid lines should also be protected from freezing because of proximity to the LH2 or SLH2 lines; a thermostatically controlled heater should be considered to provide protection. Cryogenic piping systems should not be painted white. Frost is the best indicator of insulation failure.
- Any uninsulated piping and equipment operating at LH2 or SLH2 temperatures shall be installed away from (and not above) asphalt or other combustible surfaces and protection provided for incompatible metals subject to cold embrittlement.

General criteria for safe operation of H2 pipeline

For safe operation of the H_2 pipeline system, the following considerations should be taken in account during design and installation stages:

- Local conditions e.g. seismic zone, soil characteristics.
- Applicable piping codes for mechanical design (including pressure rating and wall thickness) and installation
- Conditions of service with respect to fluid composition, gas velocity, pressure, temperature and dew point.
- Selection of metallic materials.
- Selection of nonmetallic materials.
- National laws and regulations which apply to gas transmission pipelines generally and hydrogen systems specifically
- Standards of cleanliness for service
- Industry codes of practice relating to hydrogen systems

- Hazard considerations such as flammability of Hydrogen systems

General considerations for metallic material used in H_2 pipeline…

Hardness considerations

Many metallic materials can suffer embrittlement in hydrogen gas environments. These include steels (especially high strength steels), stainless steel, and nickel alloys.

Steels used in hydrogen pipeline service should have a maximum hardness of approximately 22 HRC (Hardness Rockwell C) or 250 HB (Hardness Brinell). This hardness limit is approximately equivalent to a tensile strength limit of about 116 ksi (800 MPa). Welds should also have a maximum hardness of 22 HRC or 250 HB. It shall be noted that the welded zone is often harder and therefore more susceptible to embrittlement than the base metal.

To achieve an acceptable weld zone hardness, it may be necessary to use lower strength steels than indicated above (500 MPa). Special welding procedures and pre or post welding thermal treatments may be another approach.

In the pipeline systems, there may be a need for buffers which are usually seamless pressure vessels. Steels used for seamless vessels may have a UTS (Ultimate Tensile Strength) up to 950 MPa (ISO 9809 and ISO 11120).

The engineering alloys used in critical locations should have high toughness levels in the fabricated condition and be relatively insensitive to welding problems, e.g., hard/brittle areas, microcracks, fissures etc.

Metallurgical considerations for materials used in H_2 pipeline

- ✓ Use of alloys with homogenous fine-grained microstructures is preferred
- ✓ Avoidance of excessively hard or high strength alloys, see above.
- ✓ Use of steels with enhanced cleanliness so non-metallic inclusions, which reduce toughness and hydrogen embrittlement resistance are minimized.
- ✓ Components free from significant surface and internal defects

Metallic material used in H_2 pipeline

- ✓ Carbon Steels
- ✓ Microalloyed Steels
- ✓ Carbon-Molybdenum (C-Mo) and Carbon-Molybdenum-Chrome (C-Mo-Cr) Low Alloy Steels
- ✓ Stainless Steels
- ✓ Nickel Alloys
- ✓ Copper and Cobalt Alloys

Carbon steel is the alloy family most commonly used in hydrogen gas transmission pipelines.

- ❖ In general, the common carbon steel piping grades such as API 5L X52 (and lower strength grades) and ASTM A 106 Grade B have been widely used in hydrogen gas service with few reported problems.

- ✓ This good service is attributed to the relatively lo strength of these alloys, which imparts resistance to hydrogen embrittlement and the other brittle fracture mechanisms.

- ✓ API 5L pipe is available in two Product Specification Levels (PSL 1 and 2). PSL 2 material is advantageous for hydrogen piping.

- ✓ Heat treatment is required as this assures the presence of fine grained homogenous microstructures.

- ✓ A maximum tensile strength of 800 MPa (116 ksi) is recommended.

- ✓ It is recommended that toughness requirement be considered on certain steel mill forms to be used in hydrogen pipeline applications.

Microalloyed Steels

Large scale natural gas pipelines marked the first significant utilization of microalloyed line pipe in gas transmission applications. Since early 1990s, a significant amount of microalloyed line pipe in the API 5L X52 grade has been used to transmit hydrogen gas at pressure in excess of 7 MPa (1000 psi).

Content requirements:

- The sulfur content shall not exceed 0.01% (API 5L PSL 2 limit is 0.015%)
- The phosphorus content shall not exceed 0.015% (API 5L PSL 2 limit is 0.025%)
- The use of sulphide shape control agents such as calcium is permitted. However, all additions made for this purpose must be reported.
- The maximum carbon equivalent (CE) is 0.35 (API 5L PSL 2 limit is 0.43%)
- The concentration of any intentionally added element such as rare earths, Ti, Nb, B, Al etc must be reported. Also to be reported are any elements which affect carbon equivalent determinations.
- The final ferrite grain size shall be ASTM 8 or finer.
- Hardness shall not exceed 95HRB.
- Actual yield and tensile strengths shall be less than the following maximum above the minimum specified for different API 5L grades:

X-52 24,000 psi (165 MPa)

X-42 25,000 psi (172 MPa)

Impact test should take place and satisfy the requirements (see page 10 of the HYDROGEN TRANSPORTATION PIPELINES)

Carbon-Molybdenum (C-Mo) and Carbon-Molybdenum-Chrome (C-Mo-Cr) Low Alloy Steels

- ✓ Normally, these high temperature steels are not used in high pressure hydrogen gas transmission pipelines. Nevertheless these alloys might be welded to a gas transmission pipeline.

Nickel Alloys

- ✓ Many nickel alloys are susceptible to hydrogen embrittlement. Nickel alloys should be avoided unless the user verifies the alloy is suitable for hydrogen gas service.

Stainless Steels

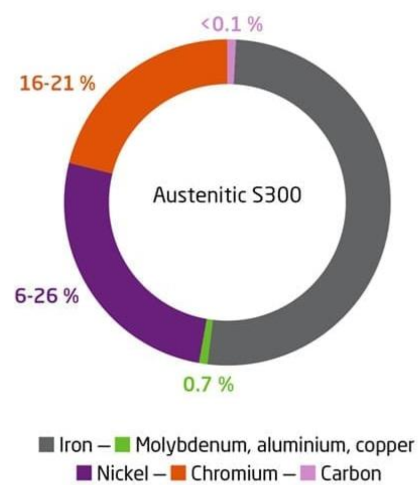
Austenitic Stainless Steels

Some of the austenitic stainless steels materials might be used to transmit hydrogen gas, particularly, at pressures at the high end of the hydrogen pressure range cited in the specification. The excellent toughness and ease of welding, particularly in field locations, are important attributes

These materials might also be used for hydrogen transmission at elevated pressures outside of the application range cited in this document. Typically, the presence of even mildly corrosive environments may require that the low carbon (304L, 316L) or stabilized grades (316Ti, 321 and 347) be used when welding is used.

For hydrogen service, stainless steels with high austenite stability are preferred (i.e. high austenite stability or high nickel equivalents).

Type 316L is preferred to 304L for hydrogen gas service because 316L has higher austenite stability and is less subject to hydrogen embrittlement.



Plastics

Nevertheless plastics exhibit varying behaviour in the presence of hydrogen. The temperatures at which the resistance of some plastics in the presence of hydrogen seems assured are:

Material	Temperature (°C)
Plasticized cellulose	20
Cellulose diacetate	20
Formo-aniline	20
Formo-urea	20
Phenol-formaldehyde	20
Furaphenol	20
Polyamides	20
Polyfuran	110
Polychloroprene	100
Polyepoxydiphenylopropane	90
Polyethylene glycol terephtalate	20
Polyurethane	20
Polyurethylmethacrylate	20
Polyvinyl acetate	20
Polyvinyl chloride	60
Polytrifluorochlorethylene	180
Polytetrafluoroethylene	250
Polyethylene	60
Polyisobutylene	100
Polystyrene	20
Polyacrylonitrile	20
Polyvinyl-vinylidene chloride (20-80%)	60

Elastomers

- ✓ Most elastomers are compatible with hydrogen.

Material	Compatibility
Natural rubber	B
Butyl rubber	A
Silicone rubber	B
Neoprene ®	A
Buna S ®	A
Hypalon ®	A
Viton ®	A
Buna N ®	A

A: good
B: fair.

Permeation of hydrogen through elastomers at 25 °C a.u.

Material	Permeation
Natural rubber	492
Butyl rubber	74
Buna S ®	399
Perbunan ® G	158
Neoprene ® G	133
Hycar or 15 ®	74
Polybutadiene	424
Polymethylpentadiene	428
Perbunan 18 ®	251
Isoprene-methacryl-nitrile copolymer	138
Hycar or 25 ®	118
Polydimethylbutadiene	172
Vulcoprene A ®	64
Isoprene-acrylonitrile copolymer	74
Thiokol S	16

References

- Empirical Profiling of Cold Hydrogen Plumes formed from Venting of LH2 Storage Vessels. https://www.nrel.gov/docs/fy18osti/68771.pdf
- https://www.api.org/~/media/files/publications/whats%20new/521%20e6%20pa.pdf
- G.R. Astbury, Venting of Low Pressure Hydrogen Gas: A Critique of the Literature, https://doi.org/10.1205/psep06054
- HYDROGEN TRANSPORTATION PIPELINES, https://h2tools.org/sites/default/files/Doc121_04%20H2TransportationPipelines.pdf
- Hydrogen Car Safety Test- Fuel Leak H2 vs. Petrol". Vimeo. Retrieved 2020-05-07.
- Explosive Lessons in Hydrogen Safety | APPEL Knowledge Services" .appel.nasa.gov.
- https://www.wermac.org/
- Hydrogen Piping and Pipelines , ASME Code for Pressure Piping, B31, https://poltar.jlab.org/filedir/Procedures/ASME%20B31.12.pdf
- SAFETY STANDARD FOR HYDROGEN AND HYDROGEN SYSTEMS https://www.energy.gov/sites/prod/files/2014/03/f11/871916.pdf

Co-funded by the
Erasmus+ Programme
of the European Union

Describe maintenance and repair procedures of high-pressure hydrogen installations in terms of inspection, grounding system, maintenance, and records

Learning Outcome 4

High pressure H_2 maintenance

In general, equipment is an all-inclusive term that includes piping, instruments, and controls as well as those hydrogen system components commonly known as equipment. Equipment inspection and maintenance can be thought of as either repairing existing equipment or replacing it in kind. Any changes made to the original installation during maintenance activities should be handled using a formal Management of Change (MOC) process.

Proper and timely inspection and maintenance is key to ensuring safe system operation. Reactive maintenance is generally unwise for equipment in hydrogen service. A systematic method should be used to evaluate a facility's equipment to develop a cost-effective approach to maintain safe, reliable operation. A maintenance plan should be documented and stewarded. A well-planned maintenance schedule (referred to as “preventative”, “routine”, or “scheduled” maintenance) should be implemented to prevent dangerous conditions before they occur. It may be acceptable to run non-critical equipment until it fails if there is redundancy in the facility and if the component failure does not pose a safety issue.

Safe maintenance for Hydrogen storage and transportation involves:

- Following good safety principles and creating a good maintenance plan.
- Developing good procedures and practices.
- Performing the right inspections at the right time.
- Providing the activities needed to keep hydrogen equipment performing properly.

General rules and considerations

A safe hydrogen system should involve**:**

- Proper design, testing, and commissioning
- Use of fail-safe features
- Preventative maintenance plan
- Written procedures
- Training for maintenance, calibration, testing, and inspection personnel

- Calibration, Testing and Inspection - The types and frequency should be consistent with applicable manufacturers' recommendations and adjusted as indicated by operating experience
- Correcting deficiencies that are outside acceptable limits
- Documentation – Each calibration, inspection, and test should be recorded
- During the design phase, project participants should ensure the appropriate safeguards and safety-related maintenance requirements are included in the design.
- Chronic maintenance issues may be the result of design flaws that should be corrected
- Any changes other than replacements in kind should be done through a formal Management of Change process.
- Workers must have the right tools and training as well as sufficient time and budget to perform needed maintenance activities

Planning for Maintenance

A complete set of maintenance plans should be drafted before the system is started. The drafts should be improved as operating experience dictates. Elements of the plan include:

- A list of equipment (See Note below.) in the facility.
- Priority grouping of equipment (high, medium, and low) based on importance to the process, safety, operability, and other key criteria. Although it is difficult to do, facility managers should balance the risk of equipment failure with the cost of maintenance. If the failure consequence of a component is minimal, inspection and maintenance need not be as frequent as those for equipment whose failure could lead to injury or shutdown.
- The required maintenance activities, manpower requirements, and timing for each component should be based on the manufacturer's recommendations, history, and good engineering judgment.
- A master maintenance schedule starting with the activities to be performed on the high-priority components. The schedule should ensure that the high-priority components receive the greatest attention before something goes wrong (preventive maintenance). It may be possible to deal with the low-priority components using in a reactive approach.
- The plan should be documented and communicated to the workers who will be performing the maintenance.

Any incident involving maintenance should be investigated following the procedures for the facility.

Integrity management of piping systems:

The integrity management process for industrial piping shall use ASME B31.8S as a basis. Compatibility of all materials used with hydrogen shall be factored into the integrity management process. This should check for the following points:

(a) external corrosion

(b) internal corrosion

(c) hydrogen-induced cracking (HIC) and consequent reduction of physical properties

(d) fatigue

(e) manufacturing defects :

(1) defective pipe seam

(2) defective pipe

(f) welding/fabrication/erection related:

(1) defective pipe girth weld

(2) defective attachment weld

(3) defective pipe threads/flange facing

(4) improperly hung/supported pipe

(g) Equipment

(1) gasket, O-ring, packing failure

(2) valve failure

(3) pressure regulator failure

(4) compressor, pump failure

(h) Mechanical damage

(1) damage inflicted by first, second, or third party with immediate failure

(2) damage with delayed failure

(3) vandalism

(i) operation

(1) incorrect or inadequate operational procedure

(j) Weather related or outside force

(1) cold/hot weather

(2) heavy rain/flood

(3) lightning

(4) windstorm

(5) earth movement

Maintenance procedure

General steps for repairing or replacing equipment in hydrogen service include:

- Preparing the system including isolating energy sources via Lockout/Tagout (LOTO) and purging hydrogen out of the equipment
- Inspection
- Doing the work
- Leak testing
- Purging air out of the equipment

Purging

- To avoid creating an explosive mixture of air and hydrogen inside any part of a hydrogen system, the air, oxygen, and any other oxidizers must be purged from the system prior to introducing the hydrogen. Similarly, when preparing a system for maintenance, the hydrogen must be purged from the system prior to opening the piping or equipment in order to avoid releasing hydrogen into the air where it could create a flammable mixture. Inert gas subsystems are typically used for these purging functions. They are also used to pressurize the system to check for leak tightness.
- The inert gases are typically nitrogen and carbon dioxide for hydrogen gas systems and helium for liquid hydrogen systems. Helium is used because at liquid hydrogen temperatures nitrogen becomes a solid.

Purging approaches

- **Flowing gas purge** uses an inert gas flowing into one part of the system and out of another part of the system. The success of this technique is dependent on the system geometry, e.g., it is more difficult to apply to a multi-branched system. Vent gases are directed to a safe location, e.g. a vent stack, to eliminate asphyxiation potential.
- **Pressurizing-venting cycle purge** uses alternating pressurizing with inert gas and venting to atmospheric pressure. This procedure stepwise dilutes the contents of a volume until the desired mixture concentration is obtained. This method can be used in systems that have long dead ends but requires pausing the purge when pressurized to allow the gases to mix. Pressurizing-venting cycle purge is typically used for purging Type IV cylinders and other components which cannot tolerate Vacuum Purging.
- **Vacuum purging** involves :

1) Venting the system to atmospheric pressure, then 2) pumping to a relatively low pressure with a vacuum pump, then 3) re-pressurized with inert gas to a positive pressure and 4) vented to atmospheric pressure. Depending on the goal of the purge and the capability of the vacuum pump, more than one cycle may be required. The vacuum pump must be suitable for the gases being evacuated, typically hydrogen, air, and the inert gas.

Standard procedures should be developed for following:

- Lockout/tagout (LOTO) – This describes the isolation of energized electrical and pressurized systems so that equipment can be worked on safely. See OSHA standard 1910.147 *The Control of Hazardous Energy (lockout/tagout)*.
- Confined space entry – This describes the need to verify a space has and will continue to have sufficient breathable air for safe entry. See OSHA standard 1910.146 Permit-required confined spaces.
- Verifying equipment is "Fit for Maintenance" – This procedure should describe inspection of equipment prior to work, depressurization of the system, purging hydrogen out of the system and testing for residual hydrogen before declaring the equipment fit for maintenance.
- Work permit – Work permits are used to control workplace hazards during maintenance. The procedure should describe how a permit is written, communicated to workers in the area, and managed across shifts.

VALVE MAINTENANCE

- Piping and Transportation Pipeline Valves
- Distribution System Valves
- Service Line Valves

TRANSMISSION PIPELINE MAINTENANCE

- Continuing Surveillance of Pipelines
- Pipeline Patrolling
- Maintenance of Cover in Cross-Country Terrain
- Maintenance of Cover at Road Crossings and Drainage Ditches.

Pressure test

Pressure Hold Period**:**

The strength test pressure shall be held for a minimum time period of 1 ⁄ 2 h.

Time Interval Between Tests**:**

The time interval between pressure tests shall be based upon an engineering critical assessment to prevent imperfections from growing to critical sizes. That engineering critical assessment shall include the following considerations:

(a) Risk to the Public.

(b) Stress Level of Previous Test.

(c) Corrosion Rate.

(d) Maintenance.

(e) Other Examination Methods.

Leakage surveys

Each operating company having a hydrogen distribution system shall set up, in its operating and maintenance plan, a provision for the making of periodic leakage surveys on the system.

The types of surveys selected shall be effective for determining if potentially hazardous leakage exists. The following are some procedures that may be employed:

(a) surface hydrogen detection surveys

(b) subsurface hydrogen detector surveys (including barhole surveys)

(c) vegetation surveys

(d) pressure drop test

(e) bubble leakage test

(f) ultrasonic leakage test

Maintenance of specific facilities

Compressor Station Maintenance:

(a) Compressors and Prime Movers.

(b) Examination and Testing of Relief Valves.

(c) Repairs to Station Piping.

(d) Isolation of Equipment for Maintenance or Alterations.

(e) Storage of Combustible Materials.

High pressure H_2 Inspection

Valve malfunctions and valve leaks are the largest contributors to hydrogen incidents at NASA, accounting for 20% of the incidents. Leaking connections are the second largest, accounting for 16% of the incidents.

Inspection activities for hydrogen systems include:

- leak testing
- checking for continuous flow from vent systems
- operational checks for valves, especially relief and check valves
- functional checks and calibration of instruments

- Leak testing using soap bubble solution or a hand-held hydrogen detector should be performed on a regular basis, and every time joints are re-assembled. Connections should be regularly inspected for any sign of corrosion, erosion, cracking, bulging, blistering, or other deterioration.
- Maintenance and recalibration of leak and flame detectors should be performed periodically, typically every 3-6 months or as recommended by the manufacturer.
- All storage and piping installations, including their components, shall be inspected before the initial operations to ensure compliance with the material, fabrication, workmanship, assembly, and test requirements. The completion of all required examinations and testing shall be verified.
- Verification shall include, but should not be limited to, certifications and records pertaining to materials, components, heat treatment, examination and testing, and qualification of welding operators and procedures
- Comprehensive control is required of all systems used in GH_2, LH_2, and SLH_2 installations. A quality control program that will satisfy the NASA requirements and engineering design for all vessels, piping, components, materials, and test equipment shall be established.
- Material identification is required for all piping and components used in fabrications and assemblies subjected to LH2 temperatures.

Non-destructive Examination Methods

Visual Examination (VT)shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP (industrial piping) or PL (pipelines), and ASME BPV Code Section V, Article 9. Records of individual visual examinations are required, which include in-process and final visual examination.

Personnel shall have an annual vision test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

Visual Examination (VT)shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP (industrial piping) or PL (pipelines), and ASME BPV Code Section V, Article 9. Records of individual visual examinations are required, which include in-process and final visual examination.

Visual examinations should verify dimensions, joint preparation (alignment, welding, or joining), and the assembly and erection of supports.

The piping and components should be examined before and during installation for the integrity of seals and other means of protection provided to maintain the special cleanliness or dryness requirements specified for LH_2 systems. Protective coverings should be examined for any damage or omission that would allow the component or piping to become wetted or contaminated beyond the limits specified in the engineering design. Components specified to be maintained under positive gas pressure should be examined to ensure conformance to the requirements.

Visual Examination Methods

DIRECT VISUAL EXAMINATION

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. (600 mm) of the surface to be examined and at an angle not less than 30 deg to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. Illumination (natural or supplemental white light) of the examination surface is required for the specific part, component, vessel, or section thereof being examined. The minimum light intensity shall be 100 fc (1 076 lx). The light intensity, natural or supplemental white light source, shall be measured with a white light meter prior to the examination or a verified light source shall be used. Verification of light sources is required to be demonstrated only one time, documented, and maintained on file.

REMOTE VISUAL EXAMINATION

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability and light intensity at least equivalent to that obtainable by direct visual observation.

TRANSLUCENT VISUAL EXAMINATION

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting, which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations.

Radiographic Examination

RT of castings is covered in para. IP-2.2.8. Radiography of welds and of components other than castings shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP or PL, and ASME BPV Code Section V, Article 2.

Radiographic Examination Technique

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

- ✓ In the single-wall technique, the radiation passes through only one wall of the weld (material), which is viewed for acceptance on the radiograph.
- ✓ Double-Wall Viewing. For materials and for welds in components 31 /2 in. (89 mm) or less in nominal outside diameter, a technique may be used in which the radiation passes through two walls and the weld (material) in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source-side image quality indicator shall be used.

Co-funded by the Erasmus+ Programme of the European Union

Radiographic Examination Double-Wall Viewing Technique

- ✓ For welds, the radiation beam may be offset from the plane of the weld at an angle sufficient to separate the images of the source-side and film-side portions of the weld so that there is no overlap of the areas to be interpreted. When complete coverage is required, a minimum of two exposures taken 90 deg to each other shall be made for each joint.
- ✓ As an alternative, the weld may be radiographed with the radiation beam positioned so that the images of both walls are superimposed. When complete coverage is required, a minimum of three exposures taken at either 60 deg or 120 deg to each other shall be made for each joint.

Ultrasonic Examination

UT of castings is covered in para. IP-2.2.8. UT of welds shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP or PL, and ASME BPV Code Section V, Article 5.

Ultrasonic Examination Technique

A pulse-echo type of ultrasonic instrument shall be used. The instrument shall be capable of operation at frequencies over the range of at least 1 to 5 MHz and shall be equipped with a stepped gain control in units of 2.0 dB or less. If the instrument has a damping control, it may be used if it does not reduce the sensitivity of the examination. The reject control shall be in the "off" position for all examinations unless it can be demonstrated that it does not affect the linearity of the examination.

**The nominal frequency shall be from 1 MHz to 5 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

Liquid Penetrant Examination

PT of castings is covered in para. IP-2.2.8. PT of welds and of components other than castings shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP or PL, and ASME BPV Code Section V, Article 6.

Liquid Penetrant Examination Techniques

Either a colour contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

(a) water washable

(b) post-emulsifying

(c) solvent removable

Co-funded by the Erasmus+ Programme of the European Union

The visible and fluorescent penetrants used in combination with these three penetrant processes result in six liquid penetrant techniques.

Liquid Penetrant Examination Techniques for standard Temperatures

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 40°F (5°C) nor above 125°F (52°C) throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 40°F to 125°F (5°C to 52°C) during the examination.

For Other temperatures follow instruction in Mandatory Appendix III of Article 6.

Liquid Penetrant Examination Technique's restriction

Fluorescent penetrant examination shall not follow a colour contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water-washable penetrants may cause loss of marginal indications due to contamination.

The maximum dwell time shall not exceed 2 hr or as qualified by demonstration for specific applications. Regardless of the length of the dwell time, the penetrant shall not be allowed to dry. If for any reason the penetrant does dry, the examination procedure shall be repeated, beginning with a cleaning of the examination surface.

Liquid Penetrant Examination,

Types of penetrants

- Water-Washable Penetrants.
- Solvent Removable Penetrants
- Post-Emulsification Penetrants.
    - Lipophilic Emulsification
    - Hydrophilic Emulsification.

Magnetic Particle Examination

MT of castings is covered in para. IP-2.2.8. MT of welds and of components other than castings shall be performed in accordance with the requirements of Part GR, the specific requirements of Part IP or PL, and ASME BPV Code Section V, Article 7.

Magnetic Particle Examination Technique

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

(a) **Particle Types**. The particles shall be treated to impart colour (fluorescent pigments, nonfluorescent pigments, or both) in order to make them highly visible (contrasting) against the background of the surface being examined.

(b) **Particles.** Dry and wet particles and suspension vehicles shall be in accordance with the applicable specifications listed in SE-709, para. 2.2.

(c) **Temperature Limitations**. Particles shall be used within the temperature range limitations set by the manufacturer of the particles.

Magnetic Particle Examination Technique

The magnetic particle examination method is applied to detect cracks and other discontinuities on the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examination's medium) to the surface. Particle patterns form on the surface where the magnetic field is forced out of the part and over discontinuities to cause a leakage field that attracts the particles. Particle patterns are usually characteristic of the type of discontinuity that is detected. Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area is to be examined at least twice, with the lines of flux during one examination being approximately perpendicular to the lines of flux during the other.

Magnetic Particle Examination Techniques

One or more of the following five magnetization techniques shall be used:

(a) prod technique

(b) longitudinal magnetization technique

(c) circular magnetization technique

(d) yoke technique

(e) multidirectional magnetization technique

prod technique

For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be applied after the prods have been properly positioned.

Yoke technique

For this technique, alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used.

e. For this technique, magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions

Longitudinal magnetisation technique

For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a longitudinal magnetic field parallel to the axis of the coil. If a fixed, prewound coil is used, the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

Circular magnetisation technique

Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a circular magnetic field that is approximately perpendicular to the direction of current flow in the part.

Multidirectional magnetisation technique

For this technique, magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions.

Eddy Current Examination

The method for eddy current examination of pipe and tubing shall follow the general guidelines of ASME BPV Code Section V, Article 8.

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, when this Appendix is specified by the referencing Code Section

PROGRESSIVE SAMPLING FOR EXAMINATION

When required random examination reveals a defect, then:

(a) two additional samples of the same kind (if welded or brazed joints, by the same welder, brazer, or operator) shall be given the same type of examination.

(b) if the items examined as required by (a) above are acceptable, the defective item shall be repaired or replaced and re-examined as specified, and all items represented by these two additional samples shall be accepted.

(c) if any of the items examined as required by (a) above reveals a defect, two further samples of the same kind shall be examined for each defective item found by that sampling

(d) if all the items examined as required by (c) above are acceptable, the defective item(s) shall be repaired or replaced and re-examined as specified, and all items represented by the additional sampling shall be accepted.

(e) if any of the items examined as required by (c) above reveals a defect, all items represented by the progressive sampling shall be either:

(1) repaired or replaced and re-examined as required, or

(2) fully examined and repaired or replaced as necessary and re- examined as necessary to meet the requirements of this Code.

(f) if any of the defective items are repaired or replaced, re-examined, and a defect is again detected in the repaired or replaced item, continued progressive sampling in accordance with (a), (c), and (e) is not required based on the defects found in the repair. The defective item(s) shall be repaired or replaced and re-examined until acceptance as specified. Spot or random examination (whichever is applicable) is then performed on the remaining unexamined joints.

Leak testing using soap bubble solution or a hand-held hydrogen detector should be performed on a regular basis, and every time joints are re-assembled. Connections should be regularly inspected for any sign of corrosion, erosion, cracking, bulging, blistering, or other deterioration.

Maintenance and recalibration of leak and flame detectors should be performed periodically, typically every 3-6 months or as recommended by the manufacturer.

Leakage testing

BUBBLE TEST — DIRECT PRESSURE TECHNIQUE

See Mandatory Appendix I of Article 10

BUBBLE SOLUTION

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. Household soap or detergents are not permitted as substitutes for bubble testing solutions. (b) The bubble forming solution shall be compatible with the temperature of the test conditions.

IMMERSION BATH

(a) Water or another compatible solution shall be used for the bath.

(b) The immersion solution shall be compatible with the temperature of the test conditions.

(c) The area of interest shall be placed below the surface of the bath in an easily observable position.

(d) The presence of continuous bubble growth on the surface of the material indicates leakage through an orifice passage(s) in the region under examination

BUBBLE TEST — VACUUM BOX TECHNIQUE

See Mandatory Appendix II of Article 10

VACUUM BOX

The vacuum box used shall be of convenient size [e.g., 6 in. (150 mm) wide by 30 in. (750 mm) long] and contain a window in the side opposite the open bottom. The open bottom edge shall be equipped with a suitable gasket to form a seal against the test surface. Suitable connections, valves, lighting, and gage shall be provided. The gage shall have a range of 0 psi (0 kPa) to 15 psi (100 kPa).

HALOGEN DIODE DETECTOR PROBE TEST

See Mandatory Appendix III of Article 10

- ✓ The more sophisticated electronic halogen leak detectors have very high sensitivity. These instruments make possible the detection of halogen gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.
- ✓ The halogen detector probe test method is a semi quantitative method used to detect and locate leaks, and shall not be considered quantitative.

HELIUM MASS SPECTROMETER TEST — DETECTOR PROBE TECHNIQUE

See Mandatory Appendix IV of Article 10

- ✓ This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in pressurized components. The high sensitivity of this leak detector makes possible the detection of helium gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures, or the determination of the presence of helium in any gaseous mixture. The detector probe is a semiquantitative technique used to detect and locate leaks, and shall not be considered quantitative.

HELIUM MASS SPECTROMETER TEST — TRACER PROBE TECHNIQUE

See Mandatory Appendix V of Article 10

- ✓ This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in evacuated components. The high sensitivity of this leak detector, when tracer probe testing, makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semiquantitative technique and shall not be considered quantitative.

THERMAL CONDUCTIVITY DETECTOR PROBE TEST

See Mandatory Appendix VIII of Article 10

- ✓ Introduction. These instruments make possible the detection of a tracer gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

- ✓ The thermal conductivity detector probe test method is a semi quantitative method used to detect and locate leaks, and shall not be considered quantitative.
- ✓ The thermal conductivity detector probe instrument uses the principle that the thermal conductivity of a gas or gas mixture changes with any change in the concentration(s) of the gas or gas mixture (i.e., the introduction of a tracer gas in the area of a leak).

HELIUM MASS SPECTROMETER TEST — HOOD TECHNIQUE

See Mandatory Appendix IX of Article 10

- ✓ The technique described in this Appendix uses the helium mass spectrometer leak detector (HMSLD) to detect and measure helium gas leakage across a boundary under test, into an evacuated space. This technique can typically be used to measure helium leakage rates of 1×10^{-4} atm cm^3 /sec to 1×10^{-11} atm cm^3 /sec (1×10^{-3} Pa m3 /sec to 1×10^{-10} Pa m^3 /sec). The high sensitivity of this helium hood leakage rate test makes it possible to detect and measure total helium mass flow across a boundary or barrier that separates a space that can be evacuated from a region containing helium gas. This quantitative leakage rate measurement technique makes it possible to determine net leakage rate by distinguishing helium leakage from pre-existing background signal.

ULTRASONIC LEAK DETECTOR TEST

See Mandatory Appendix X of Article 10

- ✓ This technique describes the use of an ultrasonic leak detector to detect the ultrasonic energy produced by the flow of a gas from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.
- ✓ Due to the low sensitivity [maximum sensitivity of 10^{-2} std cm3 /s ($^{10-3}$ Pa m3 /s)] of this technique, it should not be utilized for the acceptance testing of vessels that will contain lethal or hazardous substances.
- ✓ This is a semiquantitative method used to detect and locate leaks and shall not be considered quantitative.

HELIUM MASS SPECTROMETER — HELIUM-FILLED-CONTAINER LEAKAGE RATE TEST

See Mandatory Appendix XI of Article 10

- ✓ This technique describes the use of a helium mass spectrometer leak detector (HMSLD) to detect and measure minute traces of helium gas from a helium-filled container into an evacuated volume. The evacuated volume may be a test fixture, test device, or permanent feature of the structure being tested.
- ✓ This technique detects and measures a helium gas flow from the upstream (higher pressure) side of a boundary or barrier that separates a helium-containing volume from a region or volume that does not intentionally contain helium.

- ✓ This is a quantitative measurement technique. This technique will result in a small overstatement of leakage rate, creating a confident upper bound measurement of total leakage rate for the boundary being tested.
- ✓ This technique is particularly advantageous for leak testing sealed objects that contain helium as a condition of service, or that have helium sealed inside prior to the leak test.
- ✓ This helium-filled-container leakage rate test may be of particular advantage for detection and leakage rate measurement of a torturous path leak.
- ✓ This technique is typically limited to testing boundaries that do not include elastomers or other materials that have a high helium permeability rate.

IP & PL Testing

After construction of the piping system and after completion of the applicable examinations and repairs, but prior to the initial operation, each piping system shall be tested to ensure tightness. The test method and extent of testing shall be as required by the applicable Part IP or PL.

(a) The tests shall be in accordance with the construction organization's Quality System Program and documented procedures.

(b) The construction organization's quality control examiner shall verify and maintain record of all tests.

(c) The owner's Inspector shall verify that the tests have been completed in accordance with the requirements of this Code and the engineering design

High pressure H_2 Records

Records of testing

a) Responsibility. It is the responsibility of the construction organization (piping design manufacturer, fabricator, and erector), as applicable, to prepare the records required by the construction organization's QSP and documented procedures, along with the applicable parts of this Code, the engineering design, and the applicable requirements of ASME or ASTM standards for the specific testing methods.

b) Retention of Records. Unless otherwise specified by the engineering design, owner, or jurisdiction, the specified records shall be retained for at least 5 yr after the record is generated for the project.

High pressure H_2 Incidents case study

-HYDROGEN EXPLOSION DUE TO INADEQUATE MAINTENANCE

Severity	Leak	Ignition
Incident	Yes	Yes

Co-funded by the
Erasmus+ Programme
of the European Union

A hydrogen explosion occurred at a plant, damaging a wall adjacent to the hydrogen storage assembly. The investigation revealed that the explosion was the consequence of deficiencies in components integral to the hydrogen storage assembly, and that this assembly belonged to a supplier contracted to provide hydrogen to the plant. The analysis revealed that had the supplier properly installed and maintained this equipment, this incident would have been prevented. By receiving assurance, on an ongoing basis, that the supplier was properly maintaining this equipment, the company could have also reduced the chance of occurrence of this incident.

https://h2tools.org/lessons/hydrogen-explosion-due-inadequate-maintenance

-FUELING STATION HIGH PRESSURE STORAGE LEAK

Severity	Leak	Ignition
Incident	Yes	Yes

A hydrogen leak originating from a tank within a high-pressure storage unit serving a hydrogen vehicle fueling station resulted in fire and explosion. Emergency responders were on scene within 7 minutes and contained the fire within 3hours. No damage was reported to the separate forecourt H2 dispenser or to other major station components within the station backcourt compound. No personnel injuries resulted directly from the fire and explosion -a nearby vehicle airbag triggered due to the explosion pressure, with minor injuries to the vehicle occupants. Immediately, until root cause was determined, all potentially affected H2 stations were idled.

The root cause of the incident was subsequently identified as an assembly error of a specific plug in a hydrogen tank in the high-pressure storage unit. The inner bolts of the plug had not been adequately torqued. This led to a hydrogen leak, creating a mixture of hydrogen and air that ignited. The source of ignition has not been positively identified. An inspection and integrity verification program for the high-pressure storage units with similar plugs was implemented, including check and re-torque of tank plugs. Additional measures implemented include revised assembly, verification, and documentation procedures as well as increased automated leak detection frequency. Dependent on site, additional ignition control measures are considered, including loose gravel removal/smooth surface around the high-pressure storage unit, additional backcourt compound ventilation, and higher extent use of explosion-proof components.

https://h2tools.org/lessons/fueling-station-high-pressure-storage-leak

-PRESSURE SENSOR DIAPHRAGM RUPTURE ON H_2 COMPRESSOR

Severity	Leak	Ignition
Incident	Yes	No

The sensing diaphragm of a pressure transducer (PT), as supplied on an outdoor hydrogen compressor, unexpectedly ruptured and released approximately 0.1 kilograms hydrogen to atmosphere from the compressor discharge line. At time of incident, personnel nearby were alerted by a loud 'pop' and dust disturbance. Simultaneously, the facility monitoring system detected loss of the PT signal and initiated equipment shutdown. Facility personnel then closed isolation hand valves to stop the leak, locked and tagged out the equipment, and restricted the area. The failed component, a cigar type PT rated to 20,000 psi, originally supplied and installed by the manufacturer as part of the compressor package, was removed and inspected. Inspection revealed severed wires, a separated wire housing, missing electronics and damaged electrical potting. The PT was on a line protected by a pressure safety valve set to 15,400 psi.

Facility investigators later discovered that the failed discharge PT was manufactured with a 17-4PH stainless steel diaphragm. This type of stainless steel, while an industry standard for high pressure resistance with other materials, is known in industry to be incompatible with hydrogen. The compressor manufacturer's supplied documentation generally claimed use of materials resistant to effects of H2 embrittlement at expected operating conditions, but did not identify the specific materials of internal components such as PT diaphragms. The facility operator's commissioning procedures included functional test of each PT but did not include review of individual compressor component specifications. Subsequent communications between facility investigators and compressor representatives revealed that the compressor manufacturer did not intend to supply 17-4PH material in its compressor components; the diaphragm material was overlooked by the compressor manufacturer when sourcing the PT. The compressor was subsequently repaired with a replacement PT using Nitronic 50 material, and a compatible pressure switch hardwired to the facility 'STOP' signal was added.

https://h2tools.org/lessons/pressure-sensor-diaphragm-rupture-h2-compressor

-HYDROGEN FIRE FROM VALVE PACKING DURING MAINTENANCE SHUTDOWN AT CHEMICAL MANUFACTURING PLANT

Severity	Leak	Ignition
Incident	Yes	Yes

A chemical plant experienced a valve failure during a planned shutdown for maintenance that caused hydrogen to leak from a valve and catch fire. Four chemical reactor chambers in series were being emptied of liquid using hydrogen gas as part of a maintenance procedure. Two heater valves were opened allowing 3000 psi hydrogen to flow in reverse direction to purge the reactor system for approximately 25 minutes. At completion of the purging process, a "light" thud was heard as the reactor empty-out valves are being closed. Smoky vapor was observed coming out of one of the reactor empty-out valves and the valve closing was stopped by the operator. The operator summoned a second operator for help at which time a second "loud" thud was heard with a much larger light and dark gray vapor cloud observed coming from the leaking valve. Both operators evacuated the area and proceed to shut off the fuel supply and lower the reactor system hydrogen pressure.

Approximately two minutes after the start of this incident, the vapor cloud from the valve was replaced by a large yellow and green flame that initially engulfed a nearby separator and tank. Plant personnel began emergency fire response procedures that included closing valves to shut off hydrogen and natural gas supplies, starting the local fire fighting deluge system, bringing in an additional large fire hose, and making an emergency call to the off-site fire department. Plant personnel quenched the fire prior to arrival of the fire department. Full emergency response and incident command was established until area was declared safe. An estimated 40 lbs of hydrogen gas was released in this incident. No personnel were injured in this incident but some minor damage to nearby equipment occurred.

After the incident, the leaking valve was removed and replaced. The leaking valve was disassembled for forensic analysis. The cause of the valve failure was determined to be a packing leak in the reactor empty-out valve. The remaining valve packing was sent to vendor for failure analysis. The metallurgy of the leaking valve components was verified as being correct. Valve installation standards, specification, and records were retrieved but there was no vendor specification or standard for the valve packing.

https://h2tools.org/lessons/hydrogen-fire-valve-packing-during-maintenance-shutdown-chemical-manufacturing-plant

References

- Austin M. Glover (SNL), Jeffrey T. Mohr (NREL), Austin R. Baird (SNL), Codes and Standards Assessment for Hydrogen Blends into the Natural Gas Infrastructure, October 2021 https://www.osti.gov/servlets/purl/1871191
- Empirical Profiling of Cold Hydrogen Plumes formed from Venting of LH2 Storage Vessels. https://www.nrel.gov/docs/fy18osti/68771.pdf
- https://www.api.org/~/media/files/publications/whats%20new/521%20e6%20pa.pdf
- ASME BPV Code An International Code, 2019, https://nexnor.com/wp-content/uploads/2020/01/ASME-V-2019.pdf
- G.R. Astbury, Venting of Low Pressure Hydrogen Gas: A Critique of the Literature, https://doi.org/10.1205/psep06054
- HYDROGEN TRANSPORTATION PIPELINES, https://h2tools.org/sites/default/files/Doc121_04%20H2TransportationPipelines.pdf
- Hydrogen Car Safety Test- Fuel Leak H2 vs. Petrol". Vimeo. Retrieved 2020-05-07.
- Explosive Lessons in Hydrogen Safety | APPEL Knowledge Services". appel.nasa.gov.
- https://www.wermac.org/
- Hydrogen Piping and Pipelines , ASME Code for Pressure Piping, B31, https://poltar.jlab.org/filedir/Procedures/ASME%20B31.12.pdf
- https://h2tools.org/