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Fittings for demanding hydrogen applications

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Valves for processing hydrogen have been available on the market for many years and, in particular for cryogenic temperatures, since the 1960s. Examples of current applications can be found in the gases industry, aerospace (hydrogen and oxygen supply for launcher engines and test stands), commercial vehicles (city buses) and marine technology (fuel cell technology). In this technical report, the various requirements for valves with the hydrogen application field are explained in more detail. Particular attention is paid to future hydrogen applications, which will be considerably more technically demanding than those used to date, and this will also have an impact on the valve technology required for these applications.

The first wave of projects for future industrial applications is currently under development, and are expected to be ready for use within the next two to three years. Early uses will impact civil shipping (including ferries and hydrogen carriers), trucks and haulage, and hydrogen infrastructure (production, storage and distribution).

Other parallel developments currently in the prototype phase aren't expected to reach industrial maturity until much later. These applications include aviation (regional aircraft), rail technology and naval ships (frigates).

From our perspective as established valve manufacturers, newly emerging hydrogen applications are characterised by, among other things:

- increasing mobility and high levels of customisation
- undefined technical specifications, usage profiles and application scenarios
- undefined rules, regulations and standards for fittings relating to design, material requirements, testing and inspection.

For now, we rely on existing guidelines for pressure vessels and today's best practice.

AN OVERVIEW OF CHALLENGES FOR VALVES FOR DEMANDING HYDROGEN APPLICATIONS

Future hydrogen applications will inevitably be considerably more technically demanding – and this, of course, will drive developments in valve technology.

Today's standard, off-the-shelf products will be unable to meet many future demands, leading to a growing need for bespoke, cutting edge products.

Figure 1 highlights the vital issues to consider in the design and manufacture of valves for future applications.

Let's look at each of the requirements in the illustration above in detail.

Requirements in detail

Medium and medium temperature

The term 'hydrogen applications' covers various terms that can be differentiated according to both medium temperature (cryogenic, cold, warm) and state (liquid, gas) (**Table 1**). Hydrogen compounds are also included in a broader sense:

Material

Valves for hydrogen applications must meet both the requirements of the existing regulations (including DGRL module H and AD-2000 HP0) and extended requirements for media compatibility, while preventing the hydrogen embrittlement that occurs in the process.

Austenitic stainless steels from the 316L/N family are used to meet tightness requirements and to provide low temperature toughness at cryogenic temperatures. It's also vital to prevent cold leaks during operation – particularly those that involve an uncontrolled release of gas into the insulation vacuum.

Solid material that has been specially treated using the electro-slag remelting process (ESR) is used in place of cast stainless-steel, which is not recommended for use at cryogenic temperatures, while rolled or forged material is usually recommended for valves with large nominal widths (DN100 to DN300).

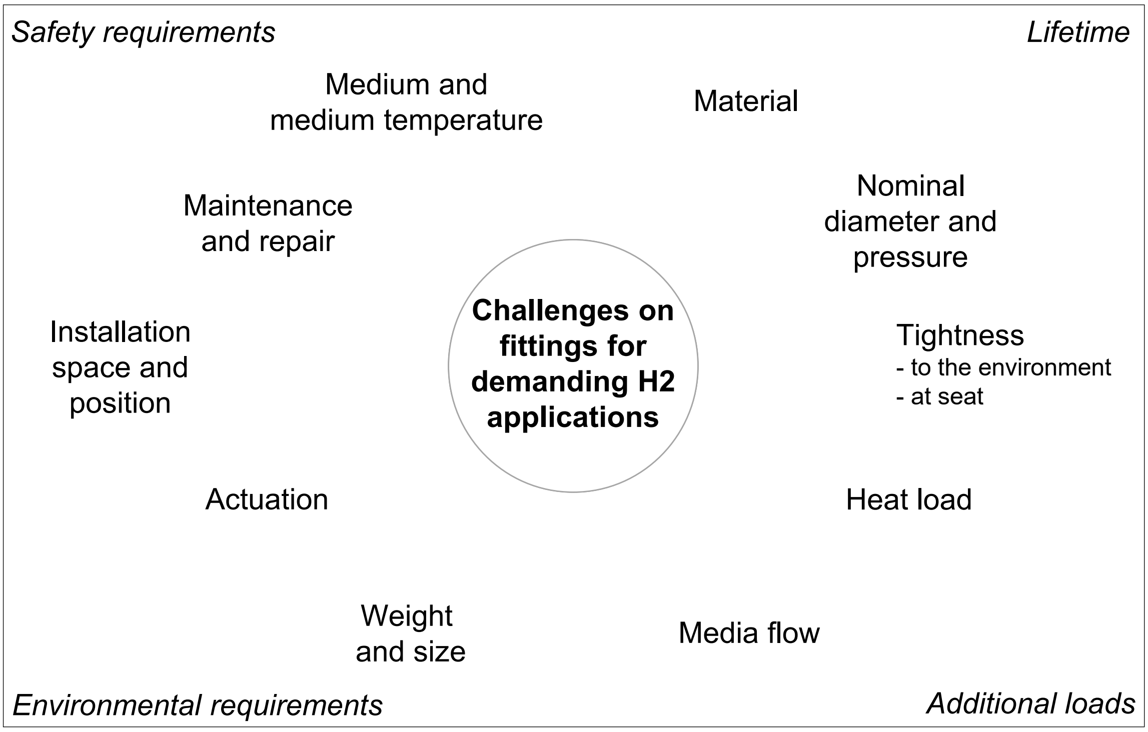


Figure 1: Essential points of attention for fittings for use in demanding hydrogen applications

Nominal diameter (DN) and pressure (PN)

Small nominal diameters (up to DN25) at low pressure levels of 5 to 10bar are commonly used for mobile hydrogen applications, such as the supply of fuel cells. Medium nominal diameters (DN25 to DN100) are used where large quantities of hydrogen are stored in combination with high flow rates and possibly high pressure levels, like in distribution centres for extraction and loading. Large nominal diameters (DN100 and beyond) are mainly used for hydrogen transport in gas pipelines and subsequent gas separation.

Bellows required for technically tight sealing to the outside are currently only available up to a maximum pressure level of PN 420bar, and so STÖHR has invested in an R&D project to develop the world's first PN 1,000bar stainless steel bellow. While future applications will require pressure levels of up to PN 1,000bar, current hydrogen projects don't yet make full use of this development, requiring shut-off at PN 500 to PN 650bar only.

Tightness to the environment

Not only is hydrogen highly flammable, it is also extremely expensive – and so leaking gas must be avoided for both safety and economic reasons. Tightness to the environment avoids the medium escaping into its immediate surroundings, while preventing the diffusion of humidity into the medium. Tight connections between the upper housing cover and the housing,

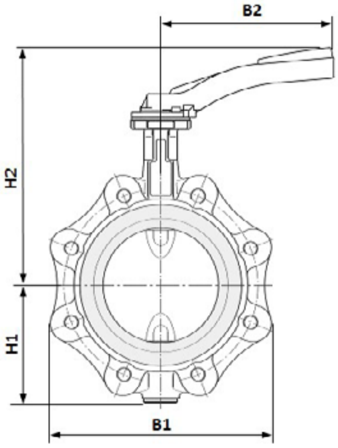
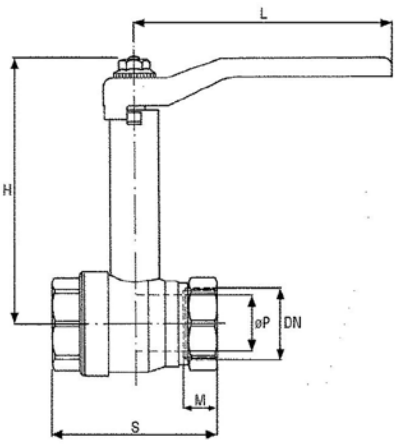
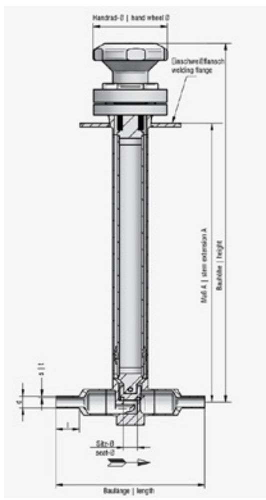
Table 1: Terms related to hydrogen applications

Labelling	Mediumtemperature [Kelvin (Celsius)]	Aggregation state	Remark
sLH_2 / LH_2	20 K (-253° C)	liquid	cryogenic liquid gas, very volatile
Cryo-compressed H2 (CcH_2)	30K bis 340K (bei Speicherdruck bis 35 MPa)	gaseous	Gas stored at high pressure level
GH_2	243 bis 323 K (-30° bis +50° C)	gaseous	Gas at ambient temperatures
„H2 ready"	0 K (273° C)	gaseous	Admixture of hydrogen, e.g. to natural gas (up to 20 percent by volume)
Methanol (CH_3OH)	338 K (65° C)	liquid	clear, odour, flammable and volatile liquid with an alcoholic odor
Ammonia (NH_3)	240 K (-33° C)	gaseous	strong pungent smelling, odour and poisonous gas

Table 2: **Leakage of different types of sealing to the outside**

Sealing	Leakage (mbar*l/sec)	Corresponds to Gas loss of
Stuffing Box Seal	1x 10^{E-3}	1 cm^3 Gas in 15 min
O-Ring	1x 10^{E-6}	1 cm^3 Gas in 10 days
Bellow	1x 10^{E-8}	1 cm^3 Gas in 3 years

Table 3: **Leak tightness at the valve seat for various types of fittings**

Valve Type	Leakage (mbar*l/sec)	Example
Butterfly Valve	1x 10^{E-3}	
Ball Valve	1x 10^{E-4}	
Seat Valve	1x 10^{E-6}	

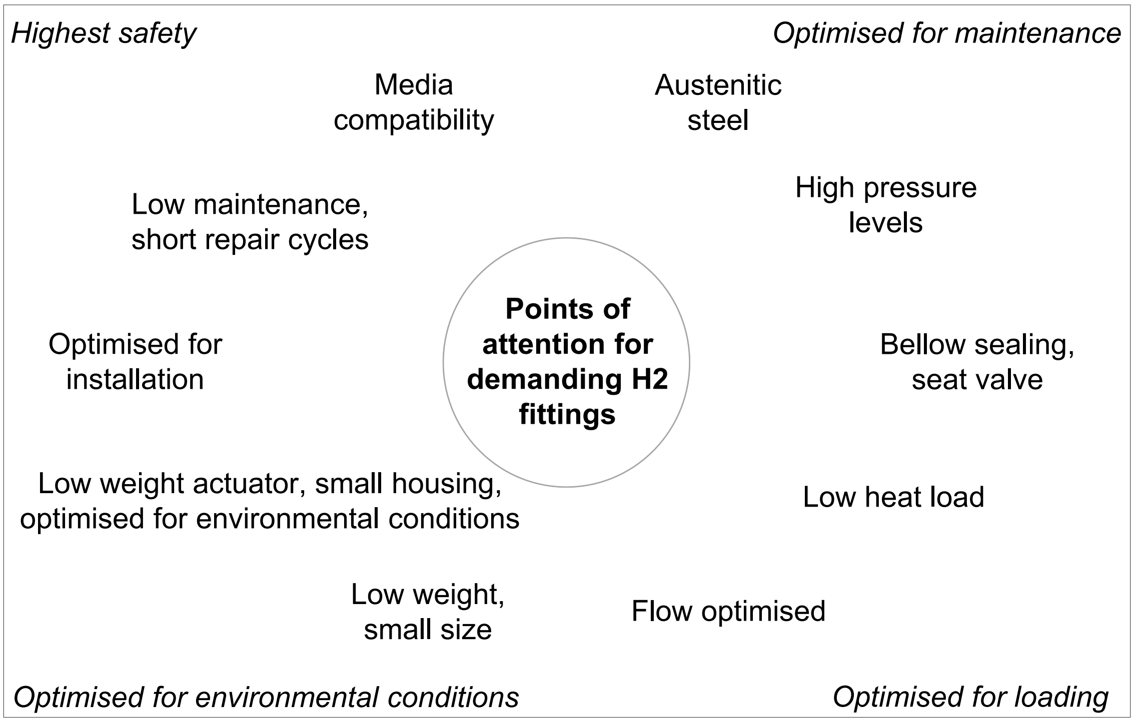


Figure 2: Summary of the essential points of attention for fittings for use in demanding hydrogen applications

and between the inlet of the valve spindle and the housing are therefore vital. In the case of mobile applications, leakage also has a negative impact on both range and operating time. Tightness against the environment depends on the type of seal used to tighten the pressure hull to the outside (**Table 2**). While the static seal between the housing cover and the housing is unproblematic, the dynamic seal between the valve spindle and the housing cover – created using stuffing box packing, an elastomer O-ring or bellows – is far more critical when it comes to preventing leakage. The use of stuffing box seal is from our point of view not recommended as it shows the lowest tightness values and is also limited in its lifetime

Tightness at seat

'Tightness at seat' describes the tightness of the valve cone in the inner valve body, which controls the media flow on or off. Tightness at seat depends on the type of seal used and the quality of the metal seat surface (**Table 3**).
Ventile mit Ventilsitz (Sitzventile) weisen (auch bei gleichem Dichtungsmaterial) eine wesentliche höhere Dichtheit zur Medienabsperrung in der Leitung auf, während Absperrklappen oder Kugelhahn mit deutlichem Abstand folgen. Bei hohen Druckstufen (PN 100 und darüber) sind Kugelhahnarmaturen nach Herstellerangaben ohnehin zur Absperrung nicht empfohlen.

Heat load

Even when the same sealing material is used, seat valves show significantly higher tightness than other valve types. Both butterfly valves and ball valves offer considerably inferior performance, and it's important to mention that ball valve fittings aren't recommended for shut-off applications at pressure levels of PN 100 and above..

Media flow

The media flow, expressed by the K_V value of the fitting (flow factor or flow coefficient, unit: m_3/h), is a measure of the achievable throughput of a liquid or a gas through a valve. The K_{VS} value – or the flow rate when the valve is fully opened – is used to specify the necessary dimension of the valves when designing the system. The higher the K_{VS} value, the greater the chance of using valves at smaller nominal diameters to achieve the desired medium flow, which contributes indirectly to the size and weight optimisation of the valve.

Weight and size

Optimising the system weight is particularly important for future mobile hydrogen applications, especially for aircraft and commercial vehicles. In addition to large components such as the tank or heat exchanger, the weight of the fittings also plays an important part in the overall weight of the system.
Those mobile applications usually come with the challenge of minimum permissible weight but also limited installation space. The smallest possible diameter of media line,

the highest possible K_{VS} value of the fitting and the lowest possible nominal pressure, all have a positive impact on the size and weight of the valve.
The forces that result from the nominal size of the media line and the media pressure determine the design of the required bellow – and the bellow, in turn, determines the size and weight of the valve used. These parameters also influence the design of the actuator with direct consequences for its housing size and weight (see Actuation, below). It therefore follows that careful design of the media flow has a significant impact on the weight and size of the valves and actuators. Additional weight optimisations for the housing – such as the use of weight-saving materials or additive manufacturing – offer comparatively little potential for optimisation.

Actuation

The total weight of a valve is largely determined by its actuator – therefore the actuator used in mobile applications using automated drives must be kept to a minimum to ensure efficient running at the lowest possible cost.
Pneumatic automated actuators offer the greatest flexibility and the most advantages, and can often be manufactured from weight-saving aluminium. Electric drives are usually limited to applications with low to medium nominal pressures (in combination with small nominal diameters) so that they can deliver the forces required to close the cone against the media pressure.
Careful design of the media flow enables the actuator to be kept to the smallest size and lowest weight possible – and has a knock-on effect on the weight of the valve itself.

Installation space and position

Valves for use at cryogenic media temperatures are specially designed for this purpose. This must be taken into account with regards to installation space and position in a mobile system, as these often have limitations.
Valves for cryogenic media temperatures are characterised by a spindle extension for thermal decoupling of the drive from the cryogenic medium, and the installation of the spindle extension in an upright position with a maximum of 30-degree lateral inclination to the horizontal line. The cryovalve can also be installed in a full horizontal position (90-degree inclination) or even upside down (180 degree inclination) but only when the valve has been custom-designed for this application.

Maintenance and repair

When it comes to maintenance and repair, fittings used in mobile hydrogen applications have additional safety-critical requirements. Such fittings are high reliability and low failure probability (MTBF), and their dependability can often be increased by duplicating critical components.
Maintenance intervals should be in accordance with the maintenance cycles customary in the industry. In aviation, this may mean changing the valve spindle once it reaches the maximum number of strokes in line with regular checks, while in transport, the maintenance interval may be determined by the customer service schedule of a truck or the average lay times of a ship at harbour.
Above all, components must be easily accessible and easy to exchange when repairs are needed. The ability to open a few screws and replace the necessary component without removing the complete valve can save time and money, as well as preventing downtime.

SUMMARY OF THE ESSENTIAL POINTS OF ATTENTION FOR FITTINGS FOR DEMANDING HYDROGEN APPLICATIONS

The following illustration provides a summary of the important issues when designing and manufacturing valves for demanding hydrogen applications (**Figure 2**).

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