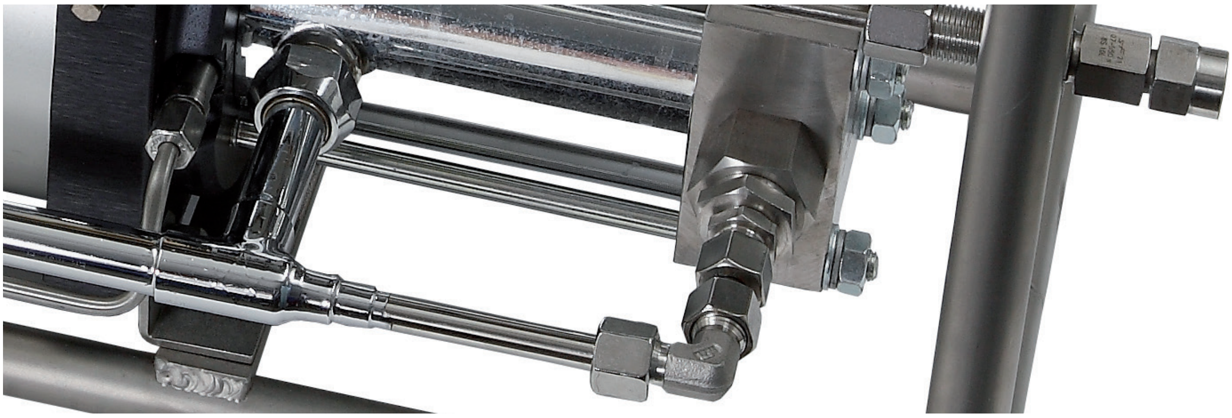
MAXIMATOR®
Maximum Pressure.



Best Practice
Hydrogen compression

Safety, explosion protection, systems engineering

What you need to know

Hydrogen is a colourless, odourless and flavourless gas and therefore cannot be detected with our human sensory organs. Hydrogen burns with invisible flame and radiates only little heat in this process.

When mixing with air in a ratio of 4 to 76 percent by volume (vol. %) of hydrogen a detonating gas develops that already can be brought to explosion by a low-energy spark.

Oxygen-hydrogen mixtures with a fraction of below 10.5 percent by volume are heavier than air and sink to the floor.

Physical and chemical properties	
Appearance:	colourless gas
Odour:	odourless
Molar mass:	2 g/mol
Melting point:	-259 °C
Boiling point:	-253 °C
Critical temperature:	-240 °C
Ignition temperature:	560 °C
Explosion limits (vol. % in air):	4 %(V) - 75 %(V)
Relative density, gaseous (air=1):	0,07
Solubility in water (mg/1):	1,6 mg/l

Safety during compression of hydrogen

Avoiding explosive atmospheres in confined spaces and outdoors.

The formation of an explosive atmosphere in adjacent areas near the hydrogen equipment is prevented by observing the following requirements:

- Hydrogen equipment shall be installed in well-ventilated areas (if possible, outdoors).
- Hydrogen equipment has to be leak-proof and remain so.
- Venting lines from safety valves, leakage lines and similar lines shall be directed into the open.
- Discharge units must not terminate below eaves, openings in buildings or placed near air intake ports.
- In case hydrogen equipment is installed in confined spaces,the gas supply coming from the outside must be provided with a reliable shut-off device placed at a safe point.
- Pipe connections on hydrogen equipment shall be fitted such that they ensure a long-term tightness of the joint.

Explosive mixture

Avoiding explosive mixtures in hydrogen equipment

Explosive mixtures cannot be tolerated in hydrogen equipment with regard to safety aspects. Such mixtures are easily ignited by e.g. the friction heat generated in activating a valve or by the friction generated by rust particles dragged through. Even the heating of the gas caused by a pressure surge during rapid inflow of hydrogen into a equipment component filled with air can induce ignition.

Prior to commissioning, the air has to be removed from the hydrogen equipment, e.g. by evacuation or flushing. The safest method is by flushing with nitrogen, when an oxygen content of below 1 percent by volume is achieved inside the plant.

When decommissioning hydrogen equipment it is necessary to render the equipment free of gas by evacuation or flushing. To achieve this, the hydrogen content must be below 1 percent by volume, before the equipment can be opened.

Please observe in all flushing procedures that flush gas always takes the path of lowest resistance. Therefore, the flush gas flow must be directed such that „dead pockets“ are avoided.

Hydrogen compression with MAXIMATOR booster

MAXIMATOR hydrogen booster design

MAXIMATOR booster are especially modified for the compression of hydrogen in the following areas:

- Material suited for pressurised components
- Sealing geometry
- Flushing Connection
- Air drive section suitable for Atex

These modifications are available for the following high-pressure sections:

- DLE 2
- DLE 5
- DLE 15
- DLE 30
- DLE 75

MAXIMATOR hydrogen boosters are marked with the suffix H2-ExIIC and are generally suited for applications in explosion class IIC.

Materials

Hydrogen places significant demand on material choice. In this area, the phenomenon of hydrogen embrittlement must be especially mentioned.

Hydrogen embrittlement describes the change in the ductility of metals. Atomic hydrogen penetrates the microstructure of metallic material. At voids or grain boundaries, the atomic hydrogen recombines to form molecular hydrogen, thus increasing the pressure inside the structure.

This process causes internal stresses and leads to material embrittlement. Material failure becomes apparent in cracks that spread outside (hydrogen-induced crack formation).

In practical tests, austenitic steel has proven to be especially successful. After high performance tests, the MAXIMATOR hydrogen booster showed no sign of hydrogen embrittlement.

Piston compressors with dynamically loaded seals are not absolutely gas-tight. To increase the performance of the piston seal for hydrogen compression purposes, both sealing geometry and material were adapted to the special requirements.

Flushing Connection

From a technical point of view, the most important part in the compression of hydrogen is to avoid the formation of explosive atmospheres. As gas leakages cannot be ruled out, MAXIMATOR hydrogen boosters have to be flushed with inert gas (preferably nitrogen) prior, during and after use.

An explosive mixture can form inside the compressor chamber, but also in the rear piston chamber due to a little leakage at the high-pressure seals.

To also provide for safe flushing of these areas, the MAXIMATOR hydrogen boosters are also fitted with an additional flushing connection. In accordance with the boosters operating principle, different flushing processes shall be carried out to ensure safe operation.

If no flushing is carried out, these areas are characterised by zone zero. In this case, MAXIMATOR boosters would belong in category 1 (which requires type approval test). In the current version, the boosters do not meet the requirements of category 1. Therefore, operation without flushing is expressly prohibited.

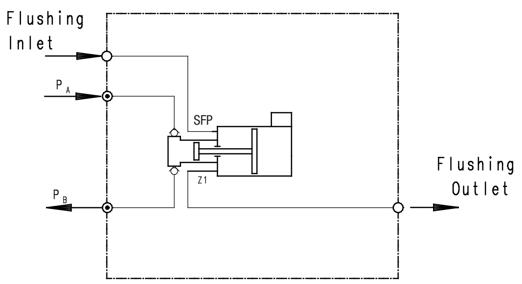
Flushing plans for MAXIMATOR hydrogen boosters

To be able to effectively flush the rear piston chamber of the booster, please observe the following installation scheme when fitting the flushing line.

It is important that there is a continuous flow of flushing gas through the flushing lines during the complete duty cycle. Make sure in particular that flushing lines are not pressurised. Otherwise this might result in damage of the high-pressure section.

Prior and after operation of the booster or equipment, the booster chamber and associated lines shall be flushed with copious amounts of nitrogen (or another inert gas). Through the flushing process it must be ensured that the oxygen content inside the booster or equipment falls below 1 percent by volume.

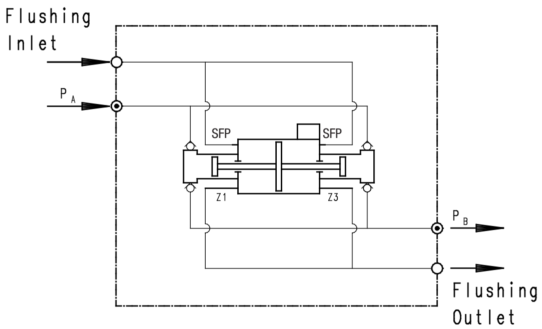
Flushing plan for single-stage, single-acting booster:



(With SFP flushing connection and Z1 leakage connection on the high-pressure side).

Flushing procedure:
1. Prior to booster start-up, connect the nitrogen supply to the inlet pressure connection (PA) and to the flushing connection (SFP).
2. Switch on the booster for approx. 1 min. (depending on the volume to be flushed).
3. Switch off the booster after completion of the flushing process.
4. Afterwards, the inlet pressure line (PA) can be connected to the hydrogen supply. During hydrogen compression, the flushing connection shall be continuously flushed with nitrogen.
5. After completion of hydrogen compression, the booster chamber shall again be flushed as described under item 2.

Flushing plan for single-stage, double-acting boosters:

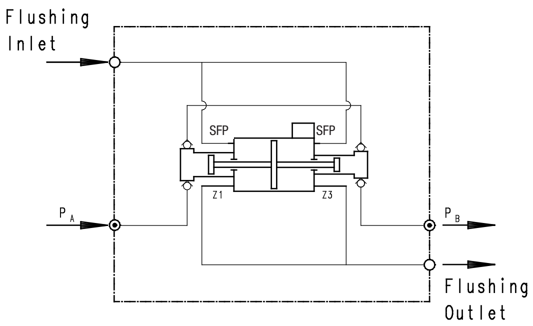


(With SFP flushing connection and Z1 and Z3 leakage connection on the high-pressure side)

Flushing procedure:
1. Prior to booster start-up, connect the nitrogen supply to the inlet pressure port (PA) and to the flushing connections (SFP).
2. Switch on the booster for approx. 1 min. (depending on the volume to be flushed).
3. Switch off the booster after completion of the flushing process.
4. Afterwards, the inlet pressure line (PA) can be connected to the hydrogen supply. During hydrogen compression, the flushing connection do not neet to be continuously flushed with nitrogen, because in single-stage, double-acting compressors no ambient air is sucked in via the leakage ports.
5. After completion of hydrogen compression, the booster chamber shall again be flushed as described under item 2.

MAXIMATOR®
Maximum Pressure.

Flushing plan for two-stage booster:



(With SFP flushing connections and Z1 and Z3 leakage connections on the high-pressure side)

Flushing procedure:

1. Prior to booster start-up, connect the nitrogen supply to the inlet-pressure port (PA) and to the flushing connection (SFP).
2. Switch on the booster for approx. 1 min. (depending on the volume to be flushed).
3. Switch off the booster after completion of the flushing process.
4. Afterwards, the inlet pressure line (PA) can be connected to the hydrogen supply. During hydrogen compression, the flushing connection shall be continuously flushed with nitrogen.
5. After completion of hydrogen compression, the booster chamber shall again be flushed as described under item 2.

Volume flow for gas flushing

Depending on the type of booster, different volume flows must be ensured to provide for sufficient flushing performance. The table below shows the minimum required volume flow.

Boosters marked in red only require volume flow during start-up and decommissioning, whereas no volume flow is required during operation.

Apart from flushing gas volume flow, the cross sections of flushing lines are also significant. We recommend not to fall below an inner diameter of 4 mm. If the diameter is smaller, this involves the hazard of gas pressure accumulating inside the flushing line. Under certain circumstances, the high-pressure component of the booster might be damaged. Also make sure the flushing line exit remains unobstructed.

Type	Flow Capacity IN/min
DLE 2-1	190
DLE 5-1	90
DLE 15-1	40
DLE 30-1	20
DLE 75-1	10
DLE 2	170
DLE 5	90
DLE 15	30
DLE 30	20
DLE 75	10
DLE 2-5	110
DLE 5-15	60
DLE 5-30	70
DLE 15-30	20
DLE 15-75	30
DLE 30-75	10
DLE 2-1-2	190
DLE 5-1-2	90
DLE 15-1-2	30
DLE 30-1-2	20
DLE 75-1-2	10
DLE 2-2	170
DLE 5-2	80
DLE 15-2	30
DLE 30-2	20
DLE 75-2	10
DLE 2-5-2	100
DLE 5-15-2	60
DLE 5-30-2	70
DLE 15-30-2	20
DLE 15-75-2	20
DLE 30-75-2	10

Temperature

Booster temperature is dependent of the medium temperature, the degree of compression and other operating conditions.

A prerequisite for safe operation is that the booster is correctly connected to earth potential.

For ideal gases, the temperature to be expected can be calculated by the following formula:

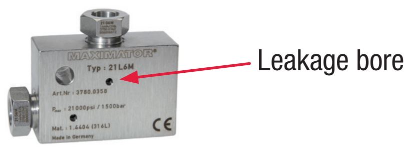
$$T_2 = \left(\frac{P_2}{P_1} \right)^{\frac{\chi - 1}{\chi}} \cdot T_1$$

with
T_2 = Temperature after compression (in K)
T_1 = Temperature prior to compression (in K)
P_2 = Pressure after compression (in bar)
P_1 = Pressure prior to compression (in bar)
χ = Isentropic exponent
The isentropic exponent for hydrogen is 1.41.

Due to the fact that compression cannot take place without a heat exchange with the environment, the actual temperature will always remain below the calculated temperature. If the temperature of the compressed gas exceeds the maximum admissible temperature, compression has to be performed in several steps, with a cooling phase in between the individual compression steps. If the temperature of the compressed gas lies below the maximum admissible temperature, you have to ensure that - in dependence with the respective explosion zone - that operating conditions do not change. A slightly less inlet pressure would result in a higher temperature!

High-pressure screw connections and hydrogen

As a rule, high-pressure screw connections (cone and thread) are suitable for hydrogen operation.
The operator of hydrogen equipment with high-pressure screw connections has to be advised that there might be possible leakage from leakage bores in fittings (t-pieces, elbows, crosspieces etc.).



If required, suitable monitoring measures shall ensure that equipment using this type of screw connection is only used when tightness of the connection is assured. The requirements are stipulated by the classification into explosion zones.

MAXIMATOR hydrogen stations

ATEX for housing and electrical cabinets

Suitability of the housing or electrical cabinets for ATEX IIC shall be separately examined for the relevant application.

As a rule, the following criteria should be met:
- Stainless steel
- no potential source of ignition
- Ventilation ports on top and at the bottom

All accessory parts have to be electrically conductive. Varnished surfaces or sight glasses normally do not meet these requirements.

In case this is required, the availability of such components (with the corresponding manufacturer's confirmation) must be checked.

Due to the material's non-conductive properties, noise insulation of the housing is also inadmissible.

Special features in project planning of hydrogen stations

Generally, the compression of hydrogen does not place special demands on safety installations. For example, the installation of additional temperature and pressure monitoring devices is normally not necessary.

In the selection of the various components (regulators, valves, filters etc.) special emphasis must be placed on their suitability for hydrogen.

In general it must be ensured that only such components are used, which do not have a potential source of ignition. The material also has to be resistant against hydrogen embrittlement. Therefore, medium-carrying lines should be of stainless steel grade 1.4404, 1.4571 or similar.

Hose lines are unsuitable for hydrogen stations according to ATEX IIC because of their lack of conductivity.

Contact Maximator:

Maximator GmbH
Lange Str. 6
99734 Nordhausen
Germany

info@maximator.de
www.maximator.de