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COmbined hybrid Solution of Metal Hydride and mechanical Compressors for decentralised energy storage and refuelling stations

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Public feedback report on the mechanical compressor

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PU	Public	**X**
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Introduction

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor.

Work Package 5 (WP5) covers the development efforts on improving state-of-the-art mechanical diaphragm compression (MC) technology on a range of operational parameters, such as efficiency, lifetime and costs.

This document serves as the deliverable D5.6 in WP5 outlining public results from the development of the MC.

Deviations

No material deviations have occurred during the execution of tasks and activities in relation to this deliverable. The WP5 activities were completed according to schedule in October 2019, however reporting submitted in November 2020, as the project activities on the MHC required an extension of the project. The extension also allow for continued activities on the MC.

Disclaimer

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1. Objectives of design and construction of the mechanical compressor

The objective of WP5 in the COSMHYC project has been to improve state-of-the-art mechanical diaphragm compression (MC) technology on a range of parameters through R&D, achieving the following targets:

- 5% efficiency improvement from 1,25 kWh/kg to 1,18 kWh/kg for 450bar inlet & 1000 bar outlet
- Improve diaphragm lifetime from 50 million to 100 million cycles – extending operation time before maintenance from ~1,5 years to ~3 years (for 4 hours of operation per day)
- Reduce noise level from 85dB to <60dB at 5 meters
- 5% cost reduction for a manufacturing volume of 50 units, from 1.000 €/(kg*day) to 750 €/(kg*day) related to a daily capacity of 200kg/day (corresponding respectively to 140 and 105 €/(kg*day) related to the peak capacity of 60 kg/h)

WP5 have involved the following five subtasks:

- Task 5.1 Development of compressor internal cooling system
- Task 5.2 Development of improved materials and surface treatment for diaphragm
- Task 5.3 Construction of prototype & noise reduction packaging
- Task 5.4 Assessment of test results and design optimization
- Task 5.5 Optimization of system design for volume manufacturing

Main and public results from each of the tasks are elaborated in following sections.

2. Task 5.1 Development of compressor internal cooling system

2.1 Objective

Current state-of-the-art diaphragm compressors do not feature internal cooling during compression. Instead temperature is typically handled before or after compression (if required for the application use). This tends to be sufficient for the traditional industrial applications with outlet pressures of around 200bar.

For hydrogen fuelling an outlet pressure of up to 950bar is however required, resulting in much more substantial heat generation. Current diaphragm compressors used for hydrogen fueling are having gas outlet temperatures of upwards 250°C resulting in a high operation temperature of the compressor system and components. This is manageable by system design, however a lower gas temperature from e.g. internal cooling could yield higher efficiency and longer lifetime.

Wear of the components is in particular affected by temperature, thus the higher temperature the components wear faster. Efficiency is also linked with the gas temperature, thus the lower gas temperature results in a higher efficiency, as the compression is closer to isothermal conditions.

The challenge for internal cooling is however to apply as much cooling surface area as possible, close to the heat source without jeopardizing the strength required to sustain the high pressure (950bar) – and achieve a cooling channel design that can be machined using standard metal manufacturing processes. Addressing of these challenges has been the objective of task 5.1.

2.2 Development of internal cooling for compressor components

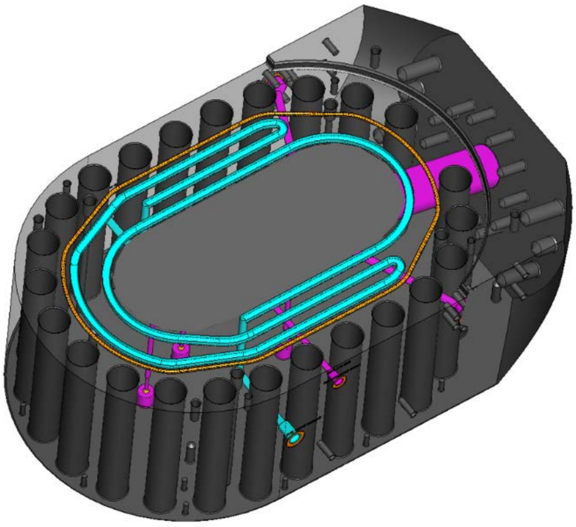
In order to develop internal cooling of critical components in the Mechanical Compressor (MC) advanced Computational fluid dynamics (CFD) and Finite Element Analysis (FEA) models of the MC was first developed.

These models were used for simulating flows, stress and temperatures in throughout the MC in order to determine where applying of cooling would yield greatest results.

On basis of the model simulations it was decided to apply internal cooling to the the compressor head as well as the piston road seal house.

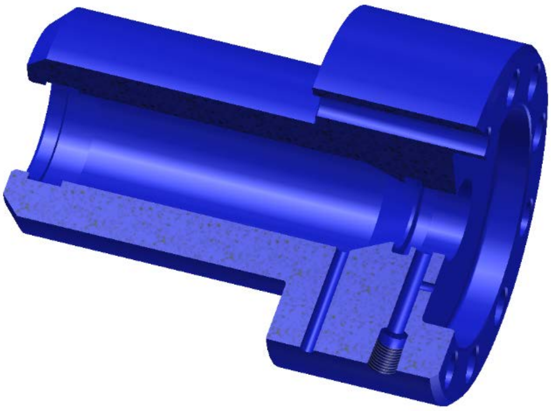
The compressor head is the component that has the greatest direct contact with the evolvement arising from the compression. Applying cooling here would provide both a direct connection with the heat source as well as potentially a high contact surface for transfer of the heat.

The picture below shows the lower part of the compressor head where internal cooling strings have been applied. The cooling strings are placed as close as possible to the compression chamber to enable an efficient and rapid transfer of heat.



Within the piston road seal house heat is also generated due to the friction caused by the movement of the piston. The motivation for applying cooling here is not to improve efficiency but primarily to reduce wear of the piston seal. Lower temperature will directly reduce wear and improve lifetime of the seal.

Picture below shows the piston road seal house where internal cooling channels were added.



2.3 Interface to overall HRS cooling system and use of heat for MHC

An interface to the overall HRS cooling system was also developed in order to feed the cooling circuits of the compressor components. Instead of having a separate cooling system for the compressor, the HRS cooling system used during fueling can also feed the compressor.

Also a technical feasibility has been conducted on potential use of the MC compression heat for the Metal Hydride Compressor (MHC).

Overall the MC compressor is expected to generate between 30-40kW of s heat generation during operation, depending of load. The glycol coolant loop will have a flow of approximately 20 liters per minute.

The MHC uses an oil based cooling system due to the high temperatures, whereas the MC currently is designed with a water based (glycol) system.

One concept considered is to have one overall oil based cooling system for both the MHC and MC. For the MC using oil instead of glycol could boost the cooling capacity achievable within the compressor head (more heat capacity and transfer). The challenge identified for this concept is however the integration with the active cooling system used during hydrogen fueling.

To comply with the SAE J2601 fueling standard, hydrogen is cooled to -40°C on the fly during fueling. This requires substantial active cooling using multi-stage cooling compressors. These compressors are sourced from conventional industries to ensure a low cost and typically operate with glycol as the first stage cooling. Redesigning the cooling compressors for oil is assed to be complicated and could increase the costs of the compressors – overall outweighing the benefits of the increased efficiency that could be gained on the compressor.

Sharing of an oil based cooling system between the MHC and MC would also require a detailed integration of both compressors, that could make a separate use of each more difficult. E.g. for centralized production use of the MHC alone is relevant, and for fueling stations with trucked-in hydrogen use of the MC alone is relevant.

Another alternative concept considered, is use of a heat pump that captures heat from the MC glycol system and “amplifies” this for use in the MHC. This would indirectly reduce the overall electrical consumption for heating of the MHC. The heat pump would allow for a more simple interface between the MHC and MC, compared to a shared oil system – thus each compressor can flexibly be used together or separately depending on the application.

Additional concepts that could be combined with the heat pump, is to add heat exchangers on the hydrogen stream, both during inter-stage and after compression. This would draw more heat out of the hydrogen gas, and further lower the gas temperature (higher efficiency and less wear). Inter-stage cooling on the MC is not within the scope of the project, as the aim is only to test one compressor head (scale 1:2). But as the MC is expanded in future projects, addition of inter-stage cooling is relevant.

3. Task 5.2 Development of improved materials and surfaces for diaphragm

3.1 Objective

Current state-of-the-art diaphragm compressors typically uses standard materials for the diaphragm with no particular advanced surface treatment. The stress levels at the typical outlet pressures of 200bar allows for such simple manufacturing approach whilst still achieving acceptable lifetime levels for industrial applications.

For hydrogen the higher outlet pressure of 950bar exposes the membrane to higher stress levels. Also the target price of hydrogen has to be much lower than for industrial purses, which requires lower operation costs. Part of this is to achieve longer lifetime to reduce the cost for diaphragm replacements.

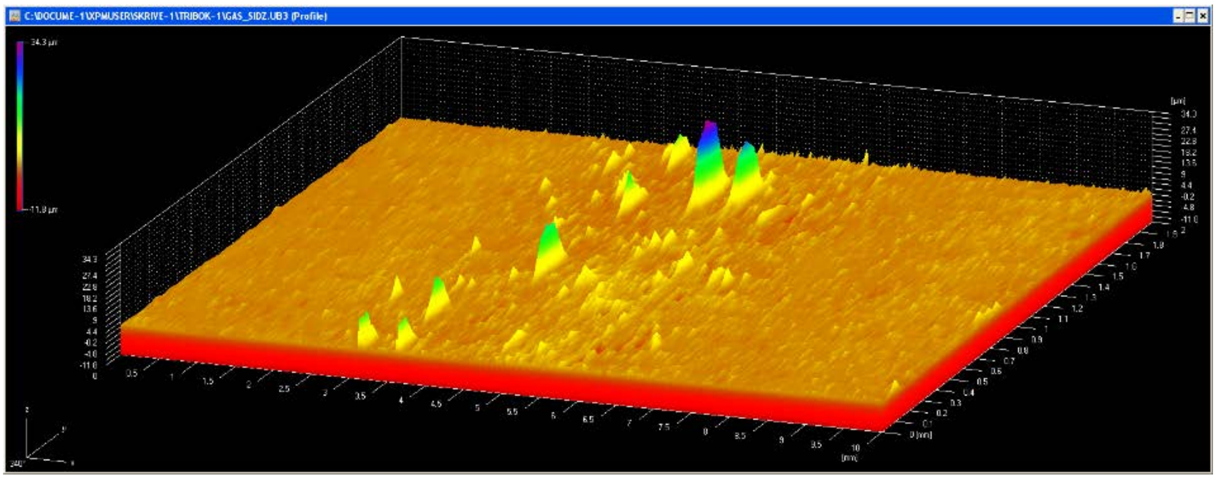
The objective of task 5.2 has been to investigate opportunities for improved manufacturing techniques of the diaphragm and surface treatments that can improve the diaphragm lifetime from 50 million to 100 million cycles.

3.2 Improved materials and surface treatment for diaphragm

The knowledge basis for failure and wear mechanisms of diaphragms for hydrogen compressors were at the time of project start limited.

To gain more knowledge on this, an extensive effort was conducted on laboratory analysis of conventional diaphragms – with the aim to identify the causes for failure and in particular the wear mechanisms.

Below picture shows a surface profile of a diaphragm.



The general observation was that standard diaphragms have a rough surface even directly after manufacturing. Small cracks and particles are visible in the surface structure caused by the heat treatment to gain high strength. As the diaphragm is used and worn, the cracks evolves into bigger cracks due to the op and down movement of the diaphragm – and eventually the diaphragm fails.

The particles caused during the heat treatment, also seems to interact with the compressor head, where the diaphragm is moving on. This friction seems to accelerate the wear of not only the diaphragm but also the surface of the compressor head.

A new diaphragm design was developed, where various type of materials and surface treatments were evaluated with regards to their ability to enable a more smooth surface. A proprietary design and material/treatment was achieved. The later prototype tests in laboratory validated the ability to reach a 100 million cycles.

4. Task 5.3 Construction of prototype & noise reduction packaging

4.1 Objective

The objective of task 5.3 has been to develop a compressor prototype that integrates the components developed in task 5.1 and 5.2. This involved developing a new power compressor frame for the crank-case and motor. Also development efforts have been conducted noise reduction to achieve 60dB at 5 meter distance compared with ~85dB for current state-of-the-art.

4.2 Development of low-noise hydraulic relief valve

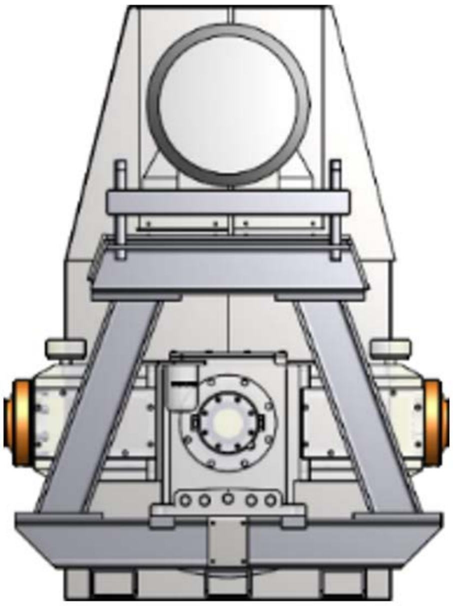
On current state-of-the-art mechanical compressors the hydraulic relief valve is used to handle the pressure fluctuations in the hydraulic oil circuit. To high pressures can cause increased stress on the diaphragm and thus increased wear.

The relief valve ensure that peak hydraulic oil pressures are reduced during operation – but this also tends to cause high pitch sounds from the valve. Compared to other noise sources in the compressor system, the high pitch sound is more difficult to contain for the equipment enclosure. Also conventional relief valves are subject to wear due to the fast movement of the springs during operation.

A completely new and proprietary design and principle for a relief valve was therefore developed. The new design features a different approach to capture the peaks in the hydraulic oil, rather causing high frequency noise from venting. The prototype tests in WP6 validated that noise emissions was greatly reduced with the new design.

4.3 Development of compressor power-frame

To assemble the various compressor components from task 5.1 and 5.2 a new compressor power-frame has been developed – see figure below.



Crank case and power frame

The power-frame houses the crank-case, electrical motor and all support balance of plant components.

The compressor heads and rod sealing house (task 5.1) is mounted onto the crank-case. The crank-case is a standard from conventional suppliers, however several few design modifications has been made to ensure easy mounting of compressor heads and components. Also the crank-case is prepared for two heads (to enable a later scale 1:1 outside of the project). When operating with two heads, a more stable operation will be achieved, reducing both vibrations and thus noise.

The electrical motor is sourced from conventional suppliers, but with a new mounting design on the power-frame that allows for use of electrical motor designs for different market regions (e.g. EU and US).

A complete balance-of-plant system has been designed and mounted onto the power-frame. This includes gas valves and pipes, hydraulic system and electrical and control cables.

The main development effort was on the actual power-frame design, where several features was desired. The power-frame is designed to house the crank-case and allow for mounting onto a concrete foundation. The power-frame is designed to channel vibrations to the foundation, thereby achieving a more smoot and less noisy operation.

Also the power-frame is designed for placement of the electrical motor on top of the crank-case. This enables a very compact footprint, compared to the typical approach of placing the motor next to the crank-case.

5. Task 5.4 Assessment of test results and design optimization

5.1 Objective

The objective of task 5.4 were to conduct iterative design optimizations of the MC based on the test results in WP6. The involved addressing issues identified during tests by improving the design followed by new and continued test – with the aim to help increase chance of achieving of the various project targets for the MC.

5.2 Design iterations and optimizations conducted

During execution of the MC prototype tests in WP6 several design iterations and optimizations were conducted on two compressor components where issues were identified during the tests.

5.2.1 Piston rod seal house

During the initial tests in WP6 great heat evolvement and thus wear were experienced on the piston road sealing. Initial road sealing designed used conventional technology as this was readily available, however it proved not to be sufficient. Instead a new proprietary road sealing design were developed where material selection and composition were optimized to reduce friction and thus heat generation and wear during operation.

Initial test run in WP6 on the new design showed reduced temperature indicating a lower friction. It was therefore decided to move on with the new design for the continued tests, which proved out to be successful.

5.2.2 Compressor head

During the initial tests in WP6 excessive wear was experienced on the middle and lower compressor head plates.

In the initial design of the compressor head no effort were put on optimizing the material and surface treatment of the head, only on the diaphragm. The rationale was that in particular the diaphragm would be exposed to great stress and the compressor head plates not to the same extent. Avoiding such activities on the head would help preserve costs.

The tests however showed that the greater wear resistance of the diaphragm increased the wear on the head, where the diaphragm rests. Indirectly the head had become the weaker part compared to the diaphragm.

It was therefore decided to also address the material and surfaces of the head. Various material and surface processes had to be tested before a suitable candidate was found and used for the continued tests, that proved to be successful.

6. Task 5.5 Optimization of system design for volume manufacturing

6.1 Objective

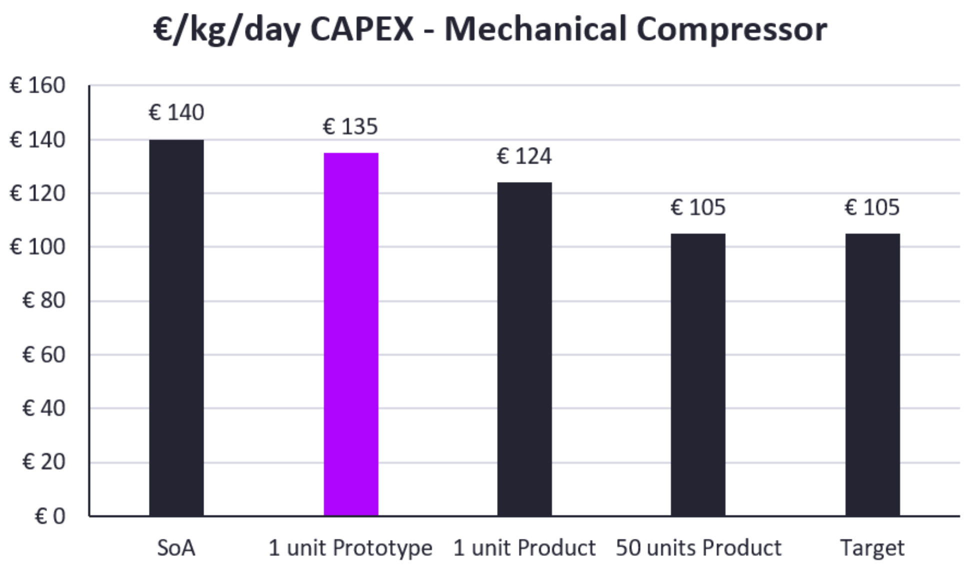
The objective of task 5.5 has been to conduct a cost reduction potential of the Mechanical Compressor when moving into high volume manufacturing. The aim is to validate that at least a 25% cost reduction is possible at 50 unit volume manufacturing per year. This would help reduce compressor CAPEX from €140 per kg per day compressor capacity down to €105.

6.2 CAPEX evolvement in relation to manufacturing volume

Current State-of-the-Art compressors comparable in scope and capacity to the developed MC has a cost level of €140 per kg per day capacity.

On the developed and tested MC prototype a cost reduction of 3,6% where achieved at €135 per kg per day, despite this only being at a prototype stage and not optimized for manufacturing. Part of this is due to the higher capacity of the compressor head relatively to the mass, but also to a large degree that more of the MC could be done in-house compared to procurement of a SoA compressor from suppliers.

The graph below show the evolvement from SoA to the 1 prototype unit, as well as the analysis outcome of potential cost reduction at manufacturing volume.



When further maturing the MC design and optimizing it for manufacturing it is expected that price can be further reduced with 7,4% to €124 per kg per day capacity at 1 unit volume. This is mainly related to savings in labor costs as a matured design will be optimized for easy and efficient assembly at factory, whereas the prototype is not. The cost reduction potential from design optimization is based on experience in NEL from previous projects where technology have been moved from the prototype stage to manufacturing ready design.

When increasing annual manufacturing volume to at least 50 units, the price can be further reduced with 16% down to the targeted €105 per kg per day. This reduction is expected to be achieved through a combination of reduced labor and component costs.

The labor cost reduction is primarily related to increase in assembly efficiency as more units are processed, as this will yield continuous learnings on where the process can be optimized. This has been experienced in the past by NEL, that time-to-assembly is greatly reduced for the first series of units being processed in the factory.

On components that price reduction is primarily related to volume. Besides volume discounts achievable on standardized components (e.g. motor, cables, pipes etc.) in particular the special designed components such as the compressor head and hydraulic system will benefit from increased volume. This will gradually allow for the supporting supply chain to mature and move the special components into becoming “standard”.