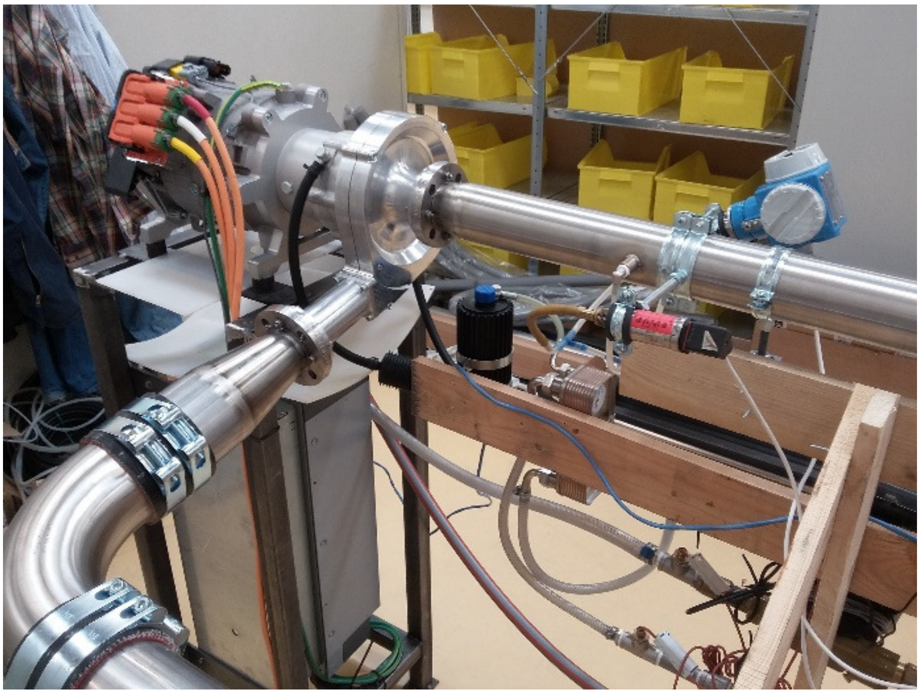
Results and experiences from operation of a steam turbo compressor in a test rig



Introduction

This Danish National Team report on Subtask 4 (Technology Development) describes and reports results from operating a high-speed turbo compressor in a test rig with steam as working medium.

The turbo compressor is developed and optimized for steam compression at pressure ratios up to 2.5 and intended for use as a high temperature heat pump capable of a temperature lift of up to approximately 25 °C upgrading industrial excess heat from a level around 100 °C. Small high-speed turbo compressors are compact with high volumetric capacity, which makes them suitable for compressing steam from a low pressure level (around 1 bara). The compactness facilitate easier integration directly at the process site between processes having excess heat (need for cooling) and process streams requiring heat at a higher temperature level.

The concept with using a turbo charger from automotive industry, designed for air, was tested by Weel & Sandvig (as a sort of proof-of-concept) back in 2011 on an industrial 4-stage evaporation plant (see picture). The compressor worked as a MVR (mechanical vapour recompression) application operating over two stages in parallel with an existing thermo-compressor (steam ejector). The test results of the compressor (Rotrex C-38) operating in steam showed good results as expected. Reporting and flyer (both in Danish) at: http://www.elforsk.dk/ELFORSK/Projekter/ProjectSearch/ProjektInfo.aspx?proji=343-005.

The project was succeed by a project (Elforsk: 343-009, with Danish Technological Institute as project holder and with more industrial partners) developing a similar type of compressor now designed for steam and with increased pressure ratio, having the impeller made by titanium alloy. The high-speed traction gear from Rotrex was still used as step-up gear with this compressor design.

The new compressor, designed for steam, was tested also at the industrial evaporating plant. However, the industrial test site was not designed for and therefore not suitable for long time test and accurate measurements for performance evaluation. During the industrial testing, the compressor revealed indication of oil/steam leakage through the high-speed compressor shaft sealing between the compressor and traction gear.

In parallel, a test facility at Spirax-Sarco in UK was established and a similar compressor was tested. This test ended after some measurements with destroying the compressor – perhaps due to unattended long time surge operation.

Later (in January 2016) Weel & Sandvig achieved financial support through the InnoBooster programme (Project: 5179-00478B) for building a test rig for long time (500 hours) test of steam turbo compressors in order to investigate performance, document durability and functionality of the compressor and drive solution. The following reporting mainly concerns the long term test project.

Aims and objectives

As described in the introduction, the proof-of-concept test showed positive results regarding compressor performance, but various reasons had limited the number of testing hours, meaning that long term performance and reliability was still undocumented with this technology. The objective is firstly to design and construct a rig suitable for long time testing and performance measurement of a steam compressor and secondly to run long time test to document the reliability of the technology e.g. the performance and durability of the high-speed shaft seal.

Participants

Weel & Sandvig in cooperation with DTU (Technical University of Denmark) providing the test facility site and integration of a student master project "Industrial High Temperature Heat Pump Development and Experimental Work", by S. K. Jóhannesson, 2017.

Budget

The total project budget of the test rig design, construction and testing approximately 199,000 Euros mainly financed by Weel & Sandvig and with financial support from InnoBooster project (5179-00478B) amounting to approximately 66,000 Euros. The project period was from January 2016 until September 2017.

Short description of compressor and gear technology

The background for using turbo compressor technology in industrial heat pumping is among others the possibility to integrate directly the heat pump within existing steam systems, supplying heat to the various process heat demands. No additional precautions need being taking when using steam as heat pump working medium, as steam is already in place. More over, steam (water) as refrigerant or working medium is abundant, has no GWP, no ODP and no harmful effects to ecosystems and humans (except for the risk of scalding from hot steam).

Figure 1. View of a cut-open traction gear (Rotrex).

Small high-speed (80-200 k rpm) turbo compressors (developed for the automotive industry for turbo-charging combustion engines) can be manufactured cheap considering their high volumetric capacity, which is required when using steam as working medium. A special high-speed traction gear (Rotrex) provides the required rotational speed.

Methodology

A test rig was designed and constructed by Weel & Sandvig. The test rig includes pressure and temperature sensors and sufficiently long measuring lines for good flow measurements. Thereby, the rig is suitable for mapping the compressor performance. In order to keep operating cost low the steam is recycled in a closed loop with de-superheating features and water/steam receiver/separator with cooling control system. Various control modes of the closed loop system were simulated in Matlab/Simulink to decide the most robust system.

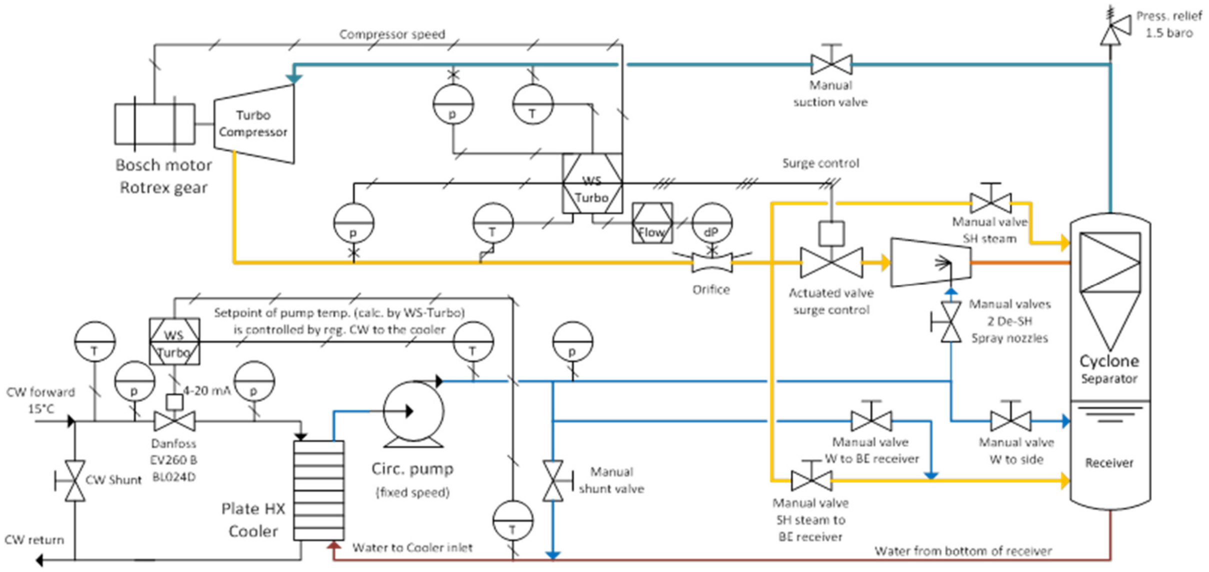


Figure 2. Principle diagram of instrumentation, cooling and control system of the Weel & Sandvig test rig.

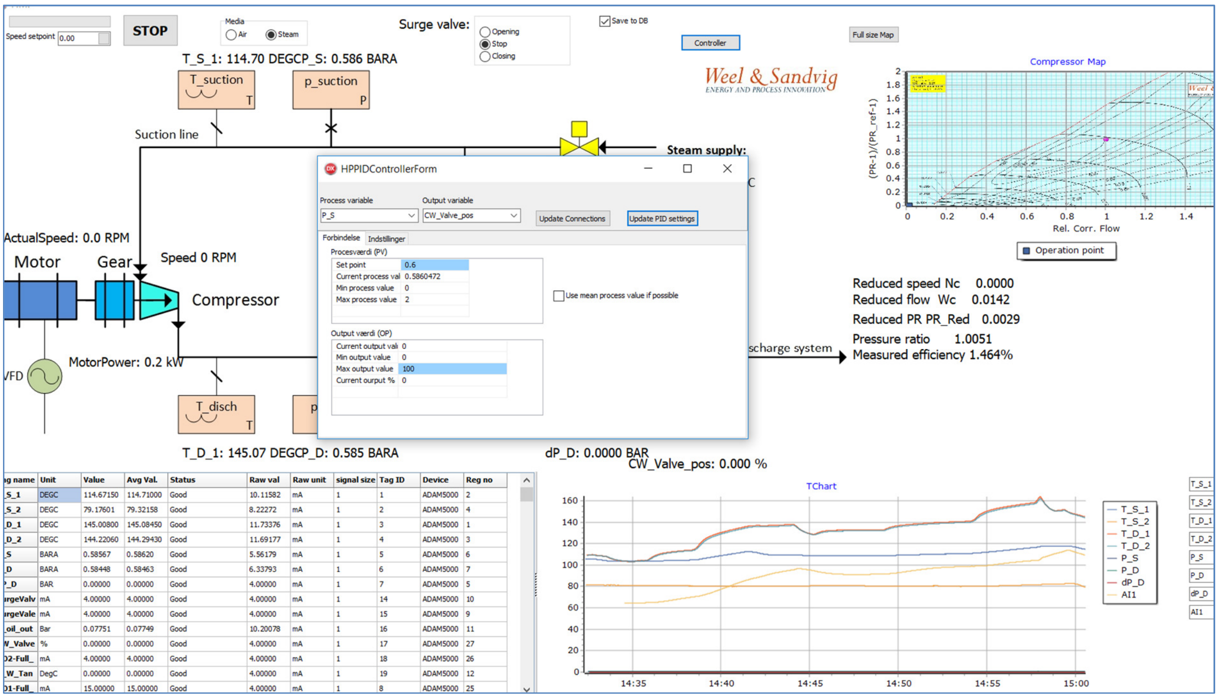


Figure 3. Screen from control system (WS-Turbo) with operating point in compressor map (upper right) and surge margin.

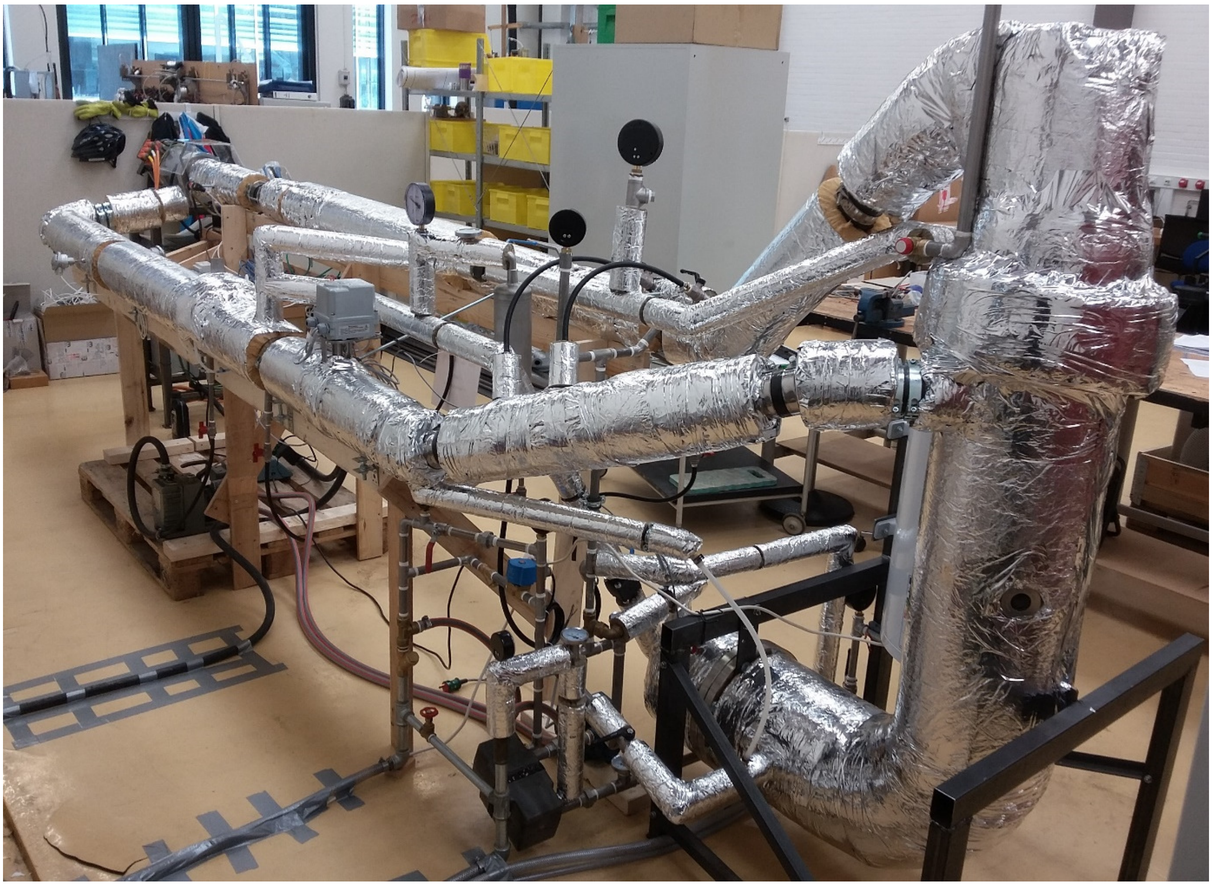


Figure 4. Weel & Sandvig steam turbo compressor test rig installed at DTU (Technical University of Denmark) lab in Kgs. Lyngby. Receiver/separator with cooling system in the foreground.

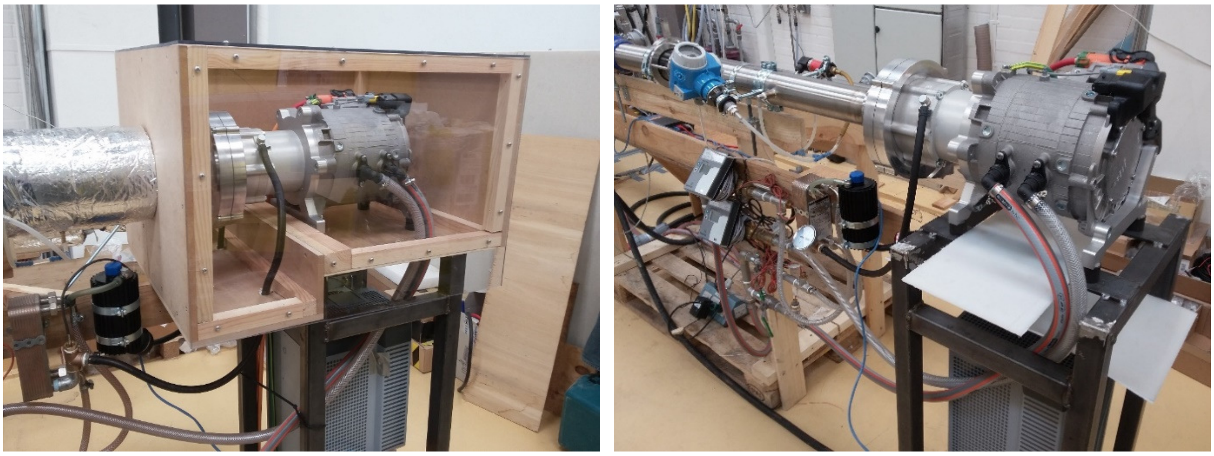


Figure 5. Water cooled 55 kW PMSM (max 12000 rpm) and Rotrex gear providing compressor speed up to 90,000 rpm. Water cooling effects to motor and gear are measured seperately.

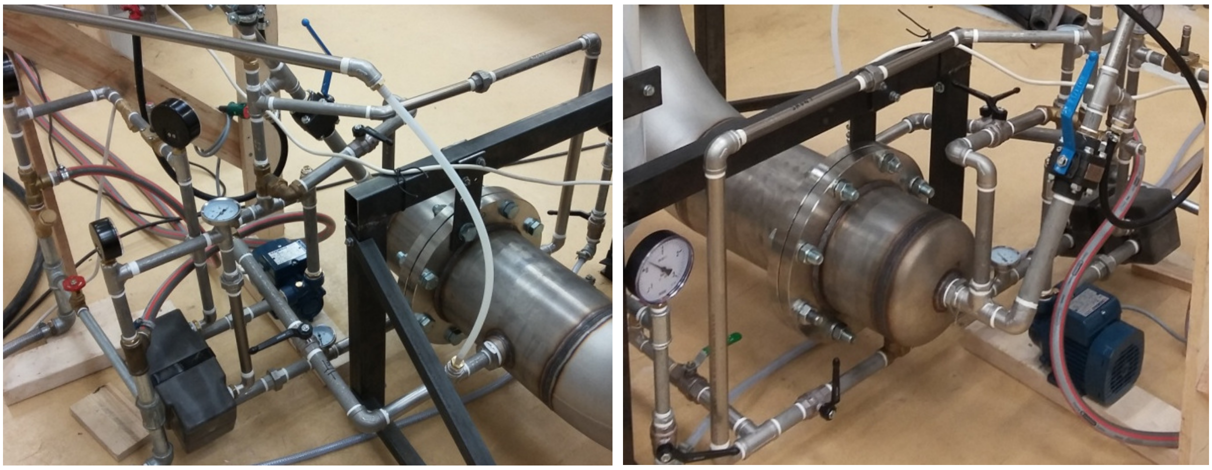


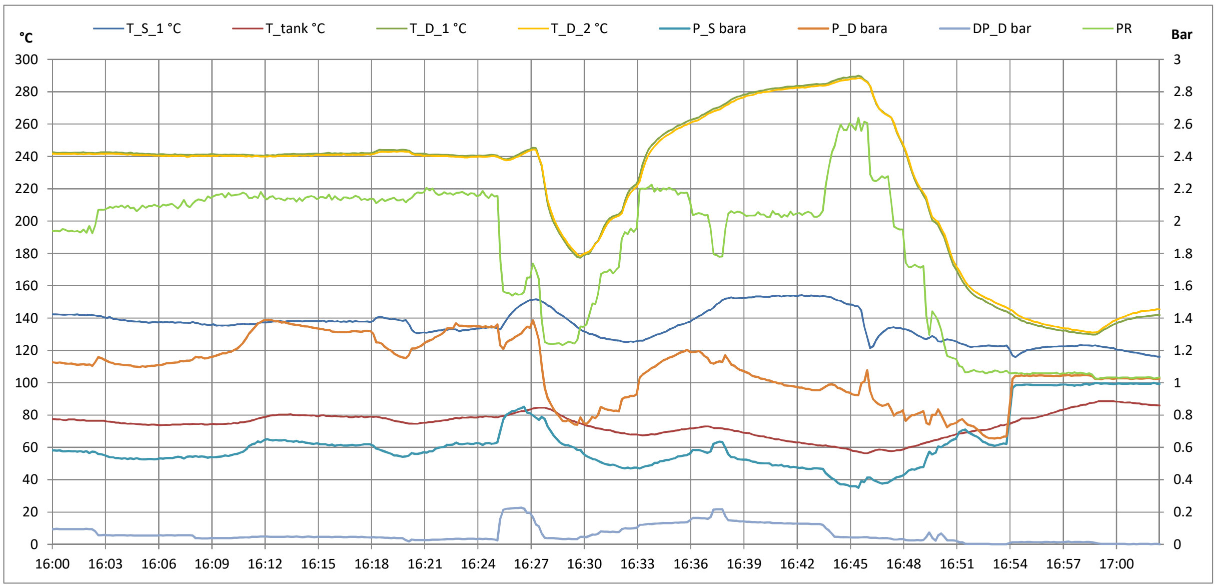
Figure 6. Cooling system on receiver/separator with pump for de-superheat nozzles and internal circulation of water.

Results

The test rig ability to de-superheat the steam has some limitations meaning that not the entire operational range (map) of the compressor can be investigated. Some modifications are required to solve this problem. However long time test is still possible. Problems however exist with the traction gear oil system in terms of:

1. The flow through the internal oil pumps (scavenger pumps) is insufficient to keep the oil temperature rise at an acceptable low level, when operating the compressor and gear at high load. The internal oil pumps in the gear (one scavenger pump for suction oil into the gear and one for discharging oil out of the gear) cannot easily be modified, as they are parts of an integrated design.
2. The sealing on the high-speed shaft between the gear and steam compressor impeller is insufficiently tight to prevent steam/water from entering the oil system. After less than 30 hours of operation, the oil has changed colour and starts to foam up when being hot (see Figure 7). Speed needs being kept below 50% of maximum in order to limit the foaming level.
3. After about 50 hours of operation increased noise level (bad sounds) from the gear is identified and no further test operation is applied. Probably the oil characteristics like e.g. viscosity have changed so much that the gear shows malfunction.

Figure 7. Water in oil system resulting in foaming and changed oil characteristic.



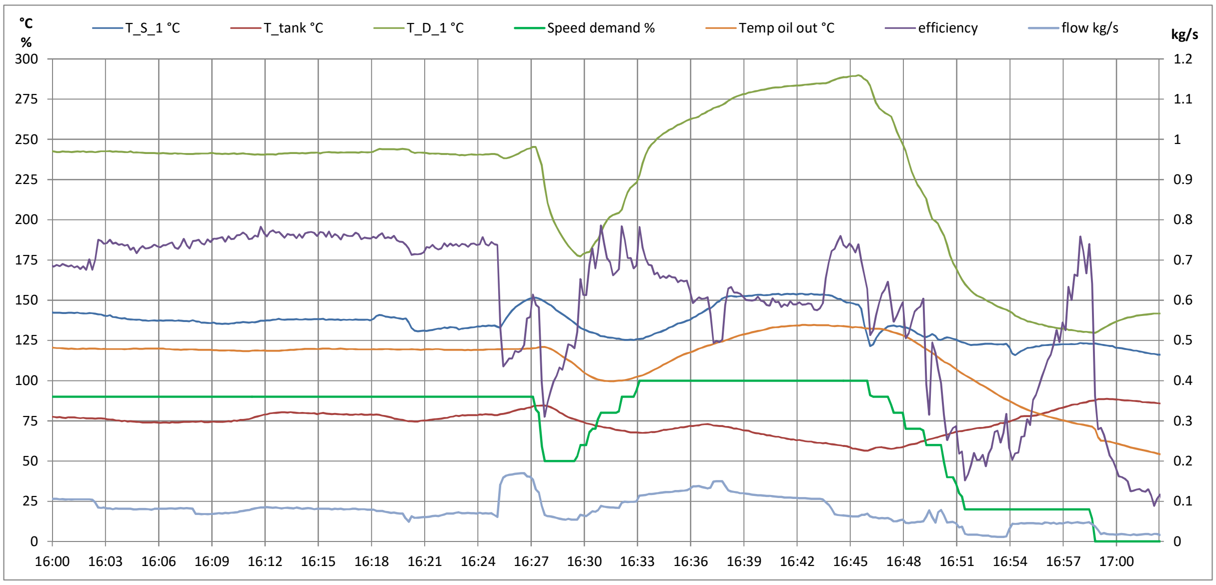


Figure 8. Example of test run (15.05.2017).

Conclusions

Based on experiences from this project we conclude that the high-speed shaft sealing has insufficient sealing capability or too short durability. A solution could be to implement a new improved sealing design for the high-speed shaft sealing e.g. as a double sealing with intermediate drainage to surroundings for ensuring that no water mixes up with oil. This will require major design change of the gear housing as there is very limited space available for the sealing in the present design.

The oil pumping capacity (flow rate) of the internal scavenger pumps are too low for ensuring a sufficient and reliable cooling of the oil flow. To change this will require a modified design of the gear.

Both design changes (improved sealing design and increased oil flow) are beyond the project resources.

Further work

If the traction gear technology from Rotrex should be considered still as an option, we suggest a modified design of the gear in terms of a larger sealing length (we recommend a double sealing with intermediate drainage) and increased oil flow capacity through the gear via external cooler.

A direct drive (high-speed motor) is an obvious alternative to using a modestly high-speed motor with a step-up gear (as in the present concept). However, still the engineering and production costs, at least for smaller production numbers, are barriers for such high-speed technology to enter the market.