Nelium turbocompressor test rig for the experimental evaluation of impeller design

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Context and test rig objectives

Within the research for a more efficient and sustainable pre-cooling cryogenic cycle for the FCC, the idea of replacing the standard screw compressor with **turbocompressor technology** emerged. This approach is however only economically viable when helium is ballasted with neon, resulting in so-called **Nelium mixture**. To determine the limitation and opportunities of designing radial compressor stages for such light gases, a turbocompressor test rig is being developed at the University of Stuttgart in cooperation with the TU Dresden. This apparatus will enable to measure and validate the performance of **novel turbocompressor designs for light gases** characterised by high rotational speeds and low design tip Mach numbers. The compressor itself and the test rig have been designed to operate within the full gas mixture range of interest for the coolant fluid of the FCC pre-cooling cycle, i.e **40 % helium up to pure helium.**

Test rig architecture and operation

The test rig can be separated in two areas:

- The first one is dedicated to the gas mixture preparation, storage and gas properties analysis. Neon and helium gas bottles are attached to a buffer tank of adjustable size. The latter is connected to a gas analyser as well as shut off valves and a pump respectively feeding or extracting gas from the test loop.
- The second area is the test loop itself, which includes the compressor operating with gas bearings and a **17 kW** high speed motor with a **rated speed of 180 kRPM**. It is followed by an aftercooler used to remove the heat generated by the compression process, a Venturi flow meter measuring the gas mass flow rate and valves throttling the flow to obtain the required compressor inlet pressure.

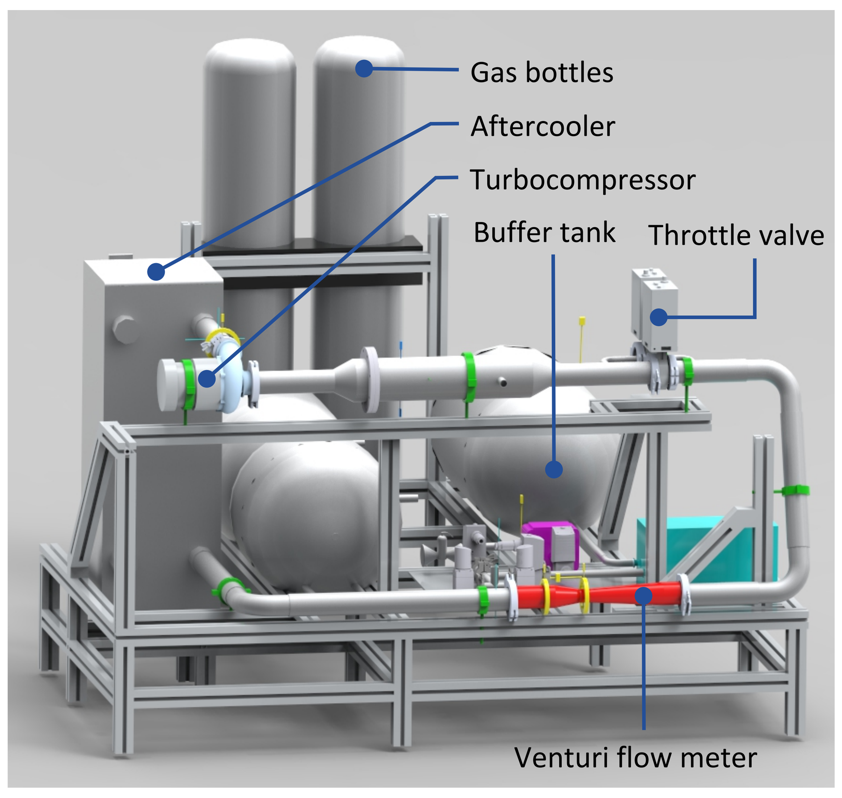


Fig 1. Test rig CAD

The test rig operation procedure is summarised below with the rig P&ID.

Gas mixture prepared by partial pressure → Mixture validated with gas analyser → Test loop filled with required mass of gas → Compressor performance map evaluated → Gas pumped to buffer tank OR Test rig vacuumed → Gas mixture prepared by partial pressure

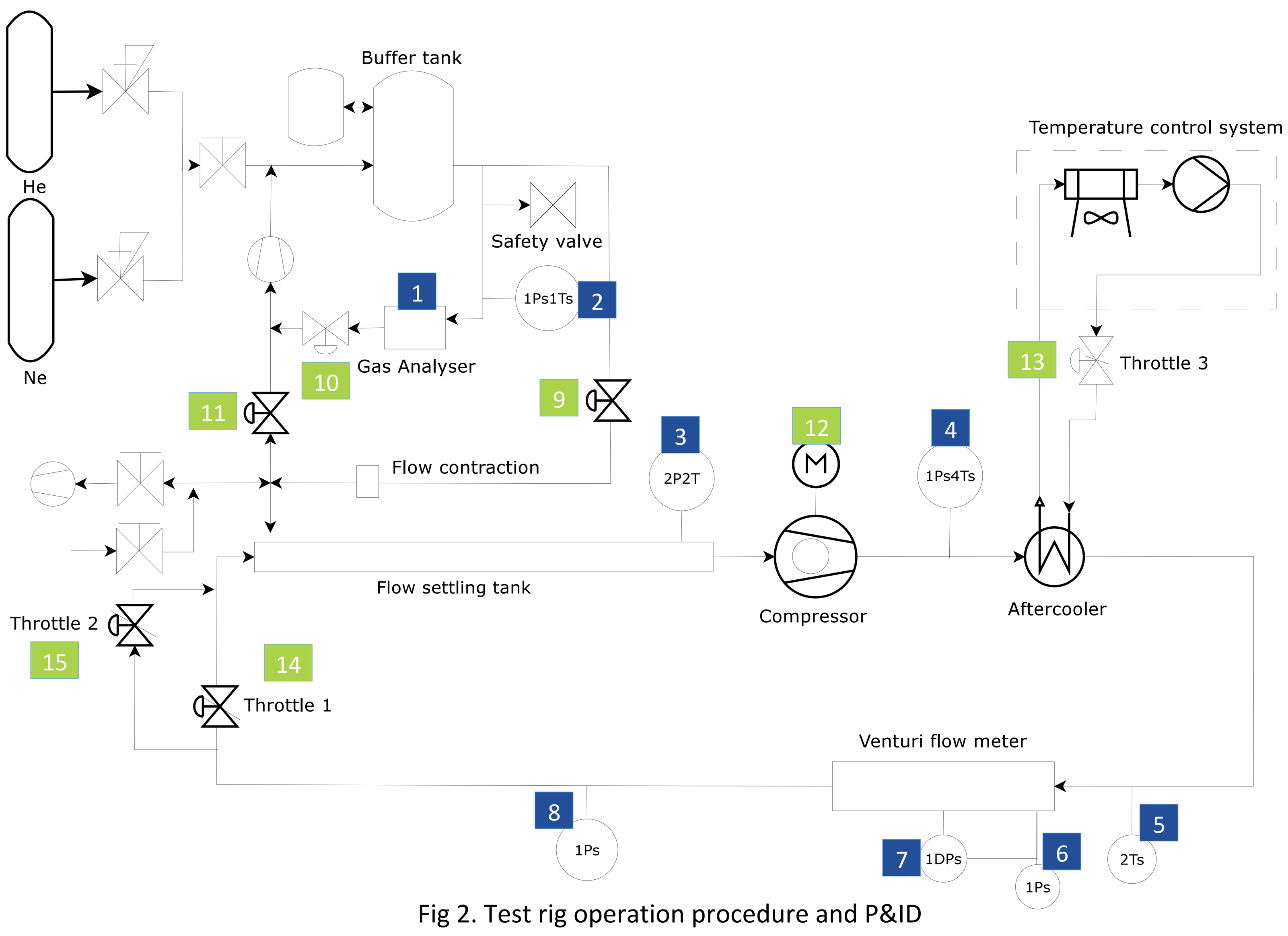


Fig 2. Test rig operation procedure and P&ID

The pressure loss accumulated through the different components is a particularly important aspect to monitor when designing a **close loop test rig**. In fact, these losses limit the range of measurable operating points in the high mass flow rate and low pressure ratio region of the compressor map. Estimating these losses is key and has been performed using a Simulink® model of the rig. This model will be calibrated further with the rig measurement data.

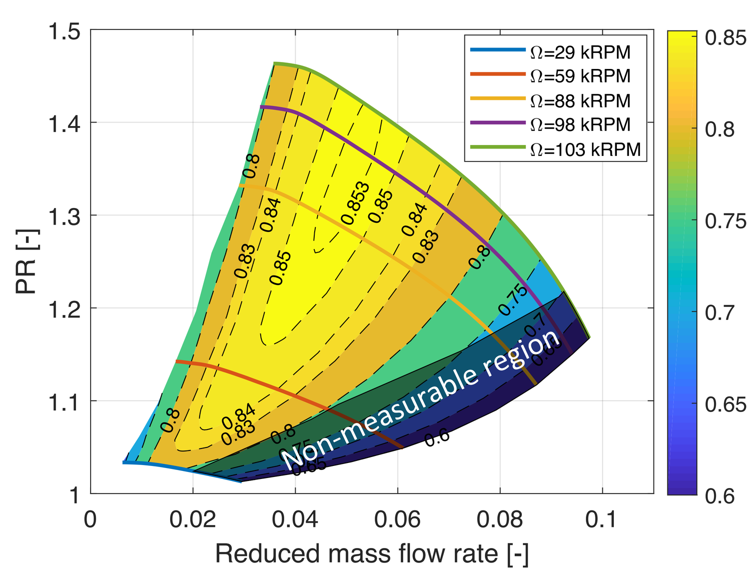
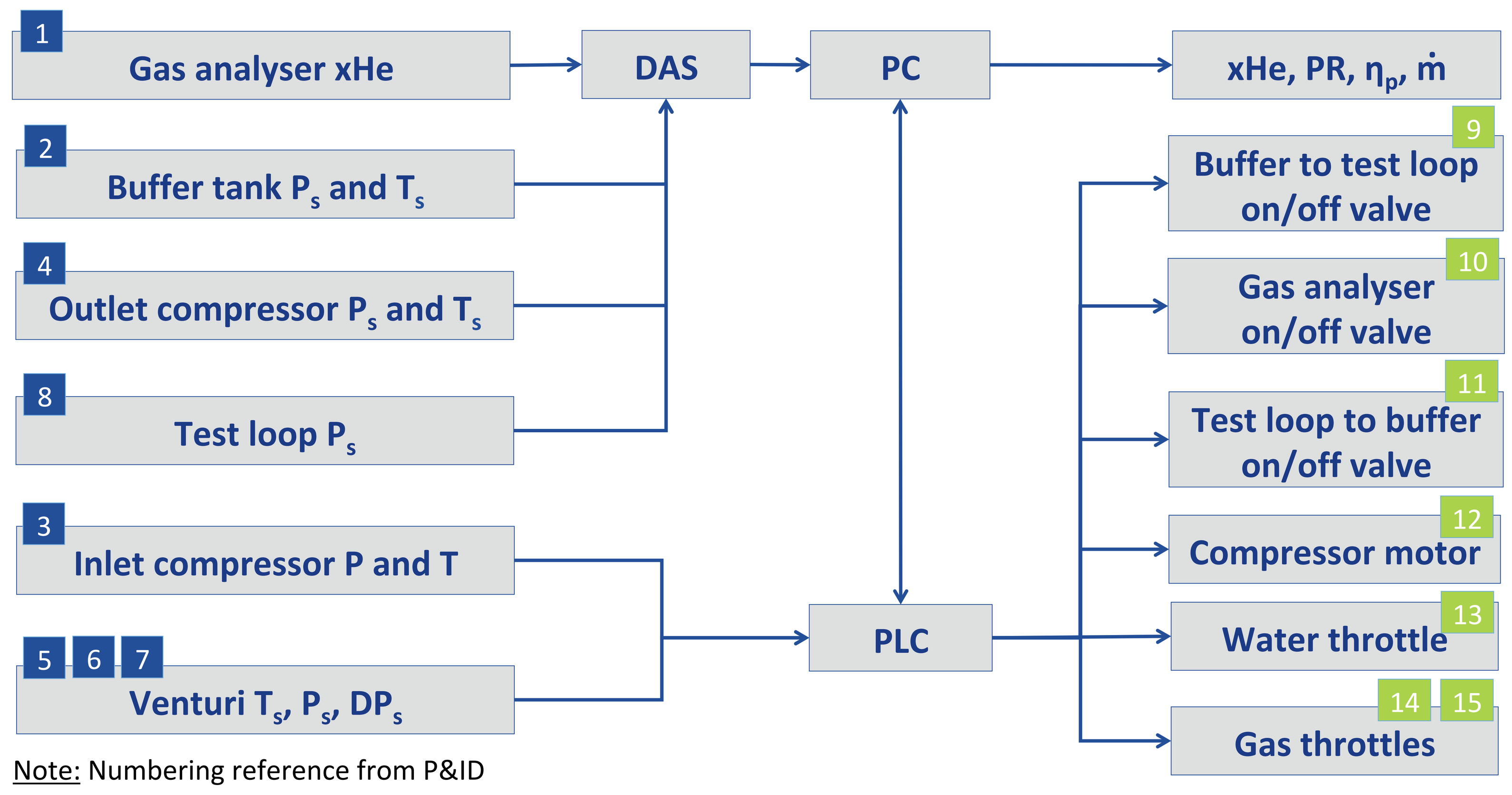


Fig 3. Non-measurable region of the compressor map

Data acquisition and rig control



Note: Numbering reference from P&ID

Current impeller design

Three different impeller designs will be tested on the rig. The first impeller has been designed to serve as an **efficient exploratory turbocompressor**. It has a design tip Mach number of 0.53 and a design flow coefficient of 0.07, enabling to operate the compressor and measure its performance for a **wide range of gas mixtures**. In addition, large mass flow rate variations can be experimentally measured with the vaneless diffuser design, synonym of **wide operating range**.

The compressor and test rig design enable to vary the gas mixtures and inlet boundary conditions and study their effect over the compressor performance. This first impeller is used to derive expressions to estimate the Reynolds number effect and later incorporate them in the performance evaluation of future designs and industrial large scale machines. This exploratory design also helps gathering experience on the test rig operation.

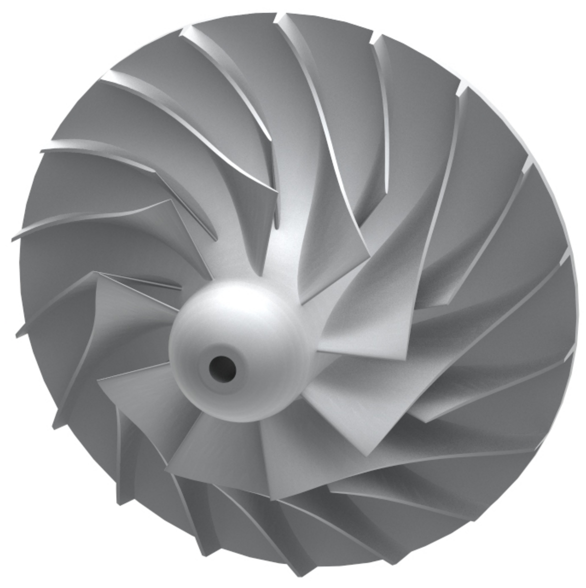


Fig 4. First impeller design

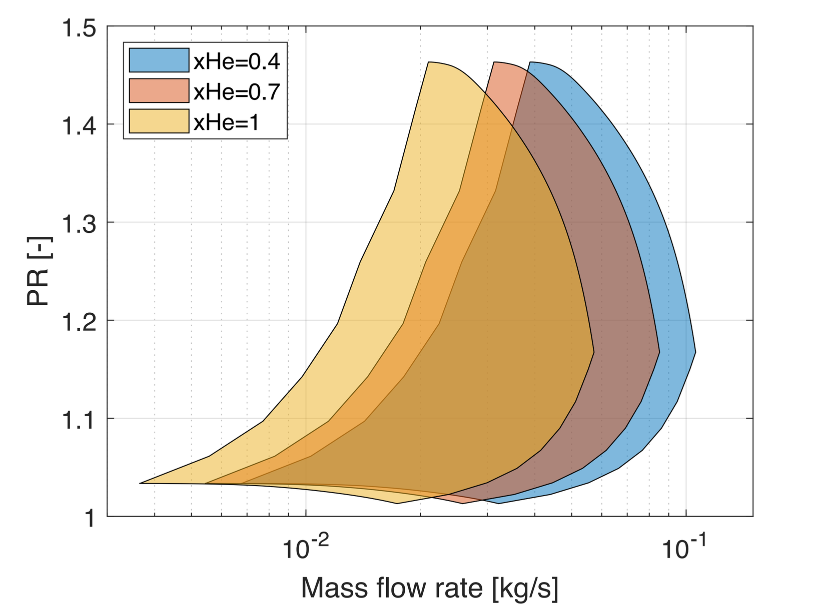


Fig 5. Compressor map envelop for different helium content

Next impeller designs

The **second impeller design** to be tested has been developed to **maximise the head coefficient** for light gases as well as to generate a geometry facilitating the rotor dynamic of the large scale multi-stage machines. The design flow coefficient and tip Mach number have been chosen to cover the entire operating condition range of the FCC multi-stage machine.

The **third impeller design** to be mounted on the rig aims at maintaining the aerodynamic performance of the second design while **supporting further the rotor dynamic** of the multi-stage machine. This requires to remove the mass, which is the furthest away from the rotational axis, resulting in a inversed splitter blade and scalloped disk design.

Fig 6. Second impeller design

Fig 7. Third impeller design

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