Design of a multi-stage turbocompressor for the FCC pre-cooling cycle

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Authors: Maxime Podeur[1], Damian M. Vogt[1]

[1]**University of Stuttgart** - Institute of Thermal Turbomachinery and Machinery Laboratory

Project description

To answer the stringent heat load specification coming from the novel architecture of the FCC, an **efficient and sustainable pre-cooling cycle** is currently being designed. In addition, the purchasing, operating and maintenance cost of the latter has to be maintained at the lowest possible level. To address this objective, one promising solution is to use a mixture of helium and neon, also called **Nelium**, as the process gas. By adding neon, acting as a ballast gas, the use of **multi-stage turbocompressor** becomes economically more viable. In fact, while standard cycles operating with pure helium use screw compressor with inherent low efficiencies, the addition of neon enables to reach higher overall machine efficiency and to increase significantly the maximum pressure ratio per turbocompressor stage. However, it is also worth noting that adding neon implies several drawbacks, the first one being the gas cost in comparison to a pure helium configuration. Secondly, when neon is added, the gas heat conductivity decreases and other components, which are part of the cryogenic cycle such as heat exchangers or cold box, become larger. Consequently, the manufacturing of these large components could become hindered or unaffordable. This poster thus provides **a solution for the compressor architecture** with today's available technology as well as **possible future improvements for an even more efficient and less costly cryogenic cycle**.

Boundary conditions

The boundary conditions required for the design of the multi-stage machine are directly derived from the particle accelerator operations. The heat load distribution on the cryogenic cycle can be estimated from machine operations as well as from the pre-cooling cycle architecture. Hence, depending on the proportion of helium and neon in the process gas, the mass flow rate, discharge pressure and gas inlet properties can be obtained at maximum load.

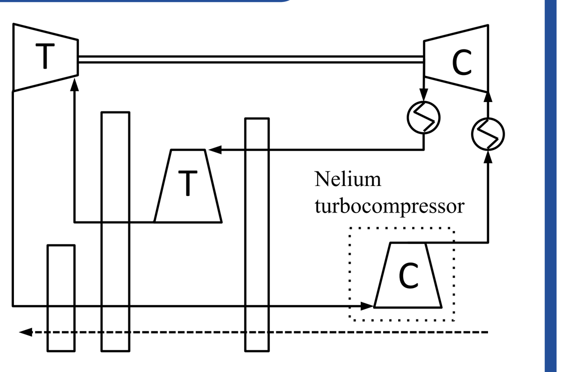

Fig 1. FCC pre-cooling cycle

Machine used

Designing a multi-stage machine for such light gases imposes several technical requirements including the **sealing capability**, the need for **high speed motors** and the capacity to **stack a high number of stages** on a single shaft with the objective of reaching the highest pressure rise per machine.

For these reasons, the so-called **HOFIM™** (High-speed Oil-Free Integrated Motor-compressor) developed by MAN Energy Solutions was selected as a particularly suitable candidate for the baseline machine. The HOFIM™ comes either in single or tandem configuration for one or two casings respectively. Machines are then positioned in series with intercoolers in between.

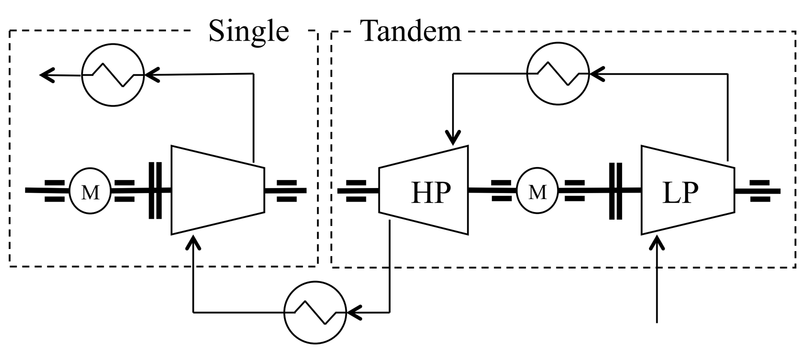

Fig 2. Single and Tandem HOFIM™ in series

Required number of machines

A study has been conducted to determine the required number of stages together with its associated number of casings and the machine cost for the whole range of gas mixture. To do so, a multi-stage pre-design tool was used to evaluate the machine aerodynamic performance and validate the rotor dynamic. Results in Figure 3 shows the **current design helium mole fraction** and the **future target gas composition** enabling to maintain the compressor and the **cryogenic cycle cost at the lowest level**.

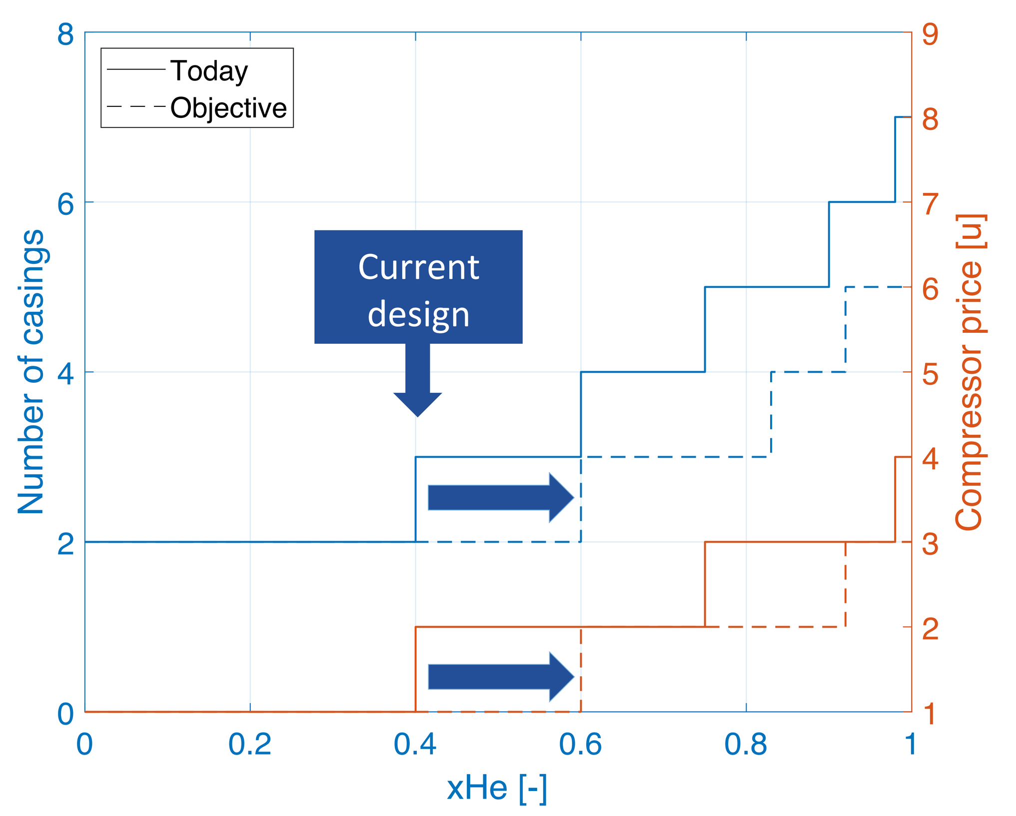

Fig 3. Required number of casings with respect to the helium content and the associated machine cost

Current machine architecture

Based on the current available technology, an architecture of a **single tandem HOFIM™** has been designed for a **maximum helium mole fraction of 0.4**. The latter is made of an LP casing composed of four 600 mm impellers and a HP casing with five 530 mm impellers. The latter has a rated speed of 9'500 RPM and is designed using two different impeller families. In fact, seven impellers are trimmed from a baseline geometry to operate within a flow coefficient range of 0.065 to 0.035 and two impellers are trimmed from a second baseline geometry to operate within a flow coefficient range of 0.035 to 0.03.

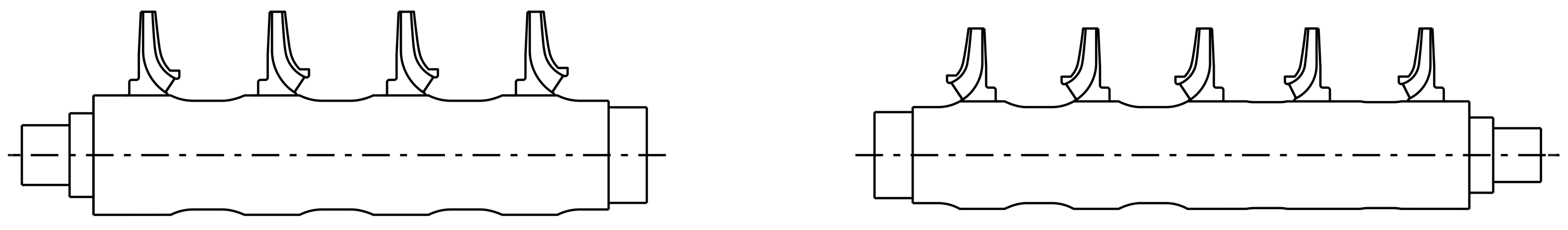

Fig 4. Current machine architecture (LP casing on the left and HP casing on the right)

Technological improvements

To achieve the objective of **increasing the helium content while keeping a single tandem HOFIM™**, several technological improvements are foreseen within the next 20 years.

Increase pressure ratio per stage	More stages on a single shaft	Reduce compression power
Casing enlargement	New impeller design	Reduce intercooler temperature
New diffuser design	Titanium impeller	Additional intercooler between stages
New motor; Bypass flow	Shaft rearrangement	

Increase xHe

Optimal cycle design:
More efficient, compact and reliable cycle & lower purchasing, operating and maintenance cost

New Impeller design

The new impeller design has to fulfil different objectives, the first one being the need of having the **same operating range** and design flow coefficient as the most used baseline impeller in the current architecture. The latter also has to achieve **at list 10% more head coefficient** as this baseline impeller, the stage polytropic efficiency has to be maintained as high as possible and the shaft diameter has to be raised as high as possible to **help the rotordynamic**. The actual novel geometry and key performance parameters obtained are given below and the performance curve are compared to the baseline impeller geometry in Figure 6.

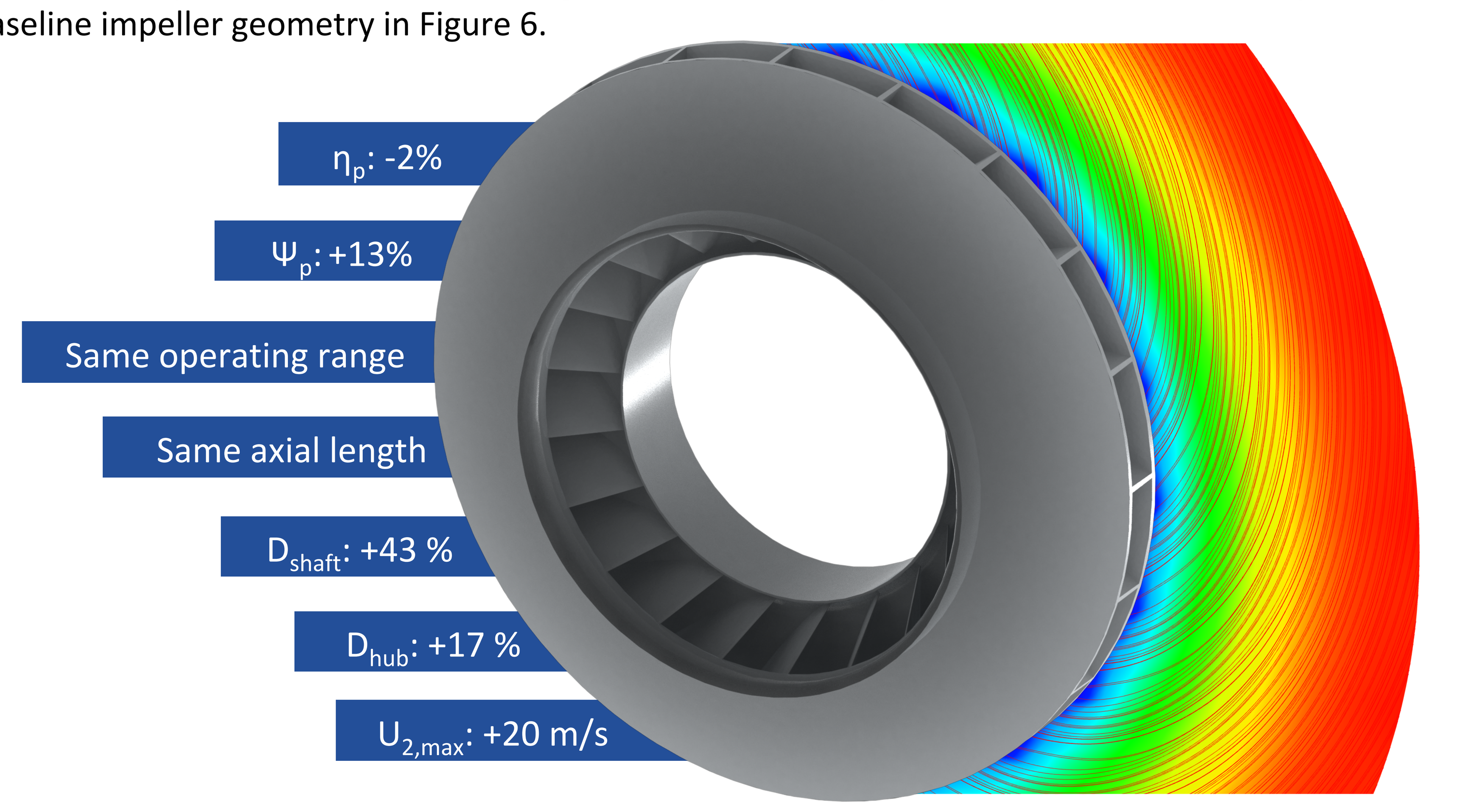

Fig 5. New impeller design with aerodynamic and rotor dynamic performance comparison to the baseline design

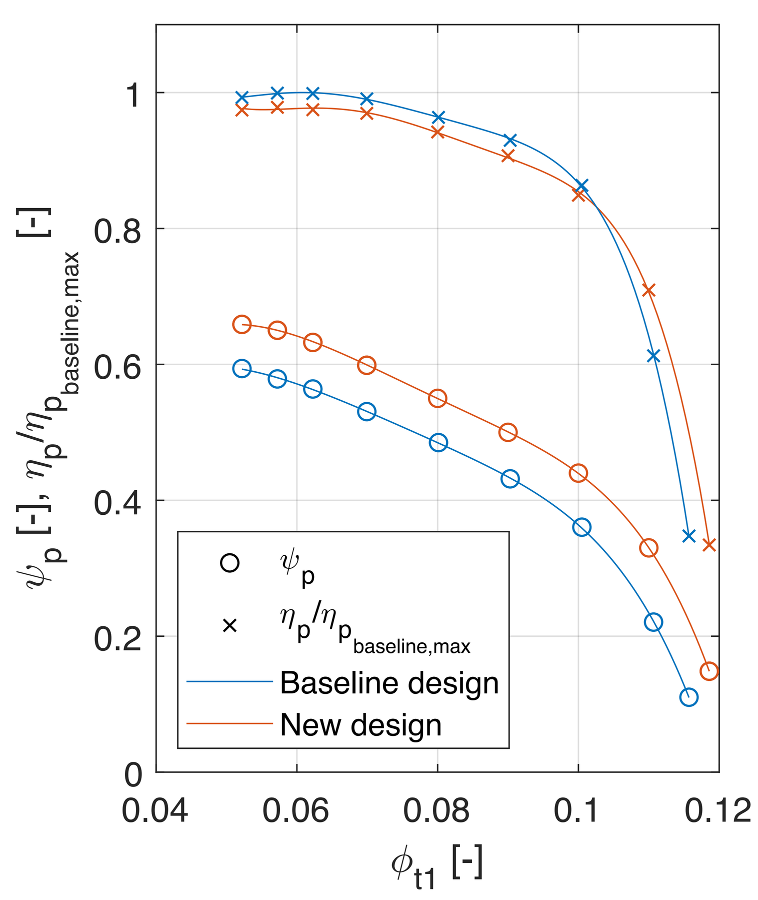

Fig 6. Aerodynamic performance comparison of new vs. baseline design

Improvements of this new design are currently understudy to help the rotordynamic. Removing material the furthest away from the rotational axis thus becomes the main objective. A design with **inversed splitter blade** and a **scalloped disk** is being investigated.

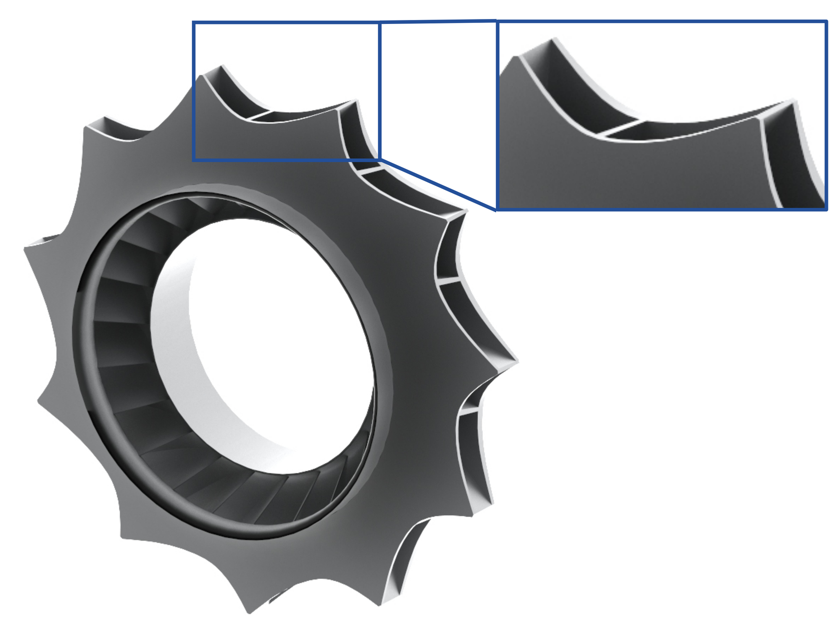

Fig 7. Inversed splitter blade with scalloped disk impeller

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