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“Development of a Nelium Turbo-Brayton cryogenic refrigerator for the FCC-hh”
EASITrain project status overview

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EASITrain – European Advanced Superconductivity Innovation and Training. This Marie Skłodowska-Curie Action (MSCA) Innovative Training Networks (ITN) has received funding from the European Union’s H2020 Framework Programme under Grant Agreement no. 764879
Outline

✓ Motivation

✓ Work performed:
  - Former cycle baseline
  - Limiting factors
  - Improved design

✓ Secondments & Trainings & Dissemination events

✓ Next steps
Motivation

Cryogenic system for the FCC-hh

Total power consumption:

\[ \sum 200 \text{ MW} : 20 \text{ MW} // 10 \text{ Plants} // 100 \text{ km} \]

Cooling capacity per plant:

- from 60 to 40 K
  - thermal shields – 78 kW
  - beam screens – 504 kW

- from 300 to 40 K
  - pre-cooling of the helium cycle – 270 kW
Baseline cryogenic cycle

Key components:

- multi-stage centrifugal compressor (~10 MW range)
- turbo-expander ~ 700 kW → power recovery in compressor

Previously considered Nelium composition: 33 vol. % of neon

Nelium Turbo-Brayton cycle: former baseline cycle layout
Limiting factors

1. Turbo-compressor design

Currently developed 1-tandem design:
- up to 40 vol. % He;
- total compressor isentropic efficiency: ~73 %

Number of required compressor casings depending on the helium content
(M. Podeur, University of Stuttgart; MAN)

2. System size and gas mass

Relative heat exchanger sizes

Theoretical relative gas mass compared to a pure helium cycle
(excluding the buffer)
Compared cycle arrangements

Cycle A (baseline)

Nelium cycle

Cycle B

Cycle C
Compared cycle arrangements

- 2 inner heat exchangers
- reduced pressure ratio
- easier pressure control
- reduced pressure ratio of pre-cooling turbine compared to cycle B
- higher pressure ratio
- additional heat exchanger
- high speed of the pre-cooling turbine (high pressure ratio)

**Cycle A (baseline)**

**Cycle B**

**Cycle C**

*Chosen arrangement*
**Compared cycle arrangements**

**Cycle C - > new baseline**

**Advantages:**
- Reduced pressure ratio
- Higher volumetric flow on the inlet of the second casing

Thus, for 40% helium:

\[
\frac{V_1 \text{ casing}}{V_2 \text{ casing}} \sim 2.4 \\
\frac{V_1 \text{ casing}}{V_2 \text{ casing}} \sim 1.9 \text{ (var)}
\]

Increase helium content up to 60 vol. % He

or

- 1 compressor impeller → +4..5 % to the total compressor $\eta_s$
**Improved cycle concept**

- **Case study (under progress):** matching the turbo-compressor middle pressure with the cycle parameters
- **Estimated total power for the chosen case:** $\sim 9.7$ MW

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26.06.2019: "Improved concept of the Nelium Turbo-Brayton cycle for the FCC-hh beam screen cooling".
S. Savelyeva, S. Klöppel, Ch. Haberstroh, H. Quack
Upper heat exchanger design

Reduction of the heat exchanger cross-section area and the cold box diameter

New baseline cycle flow diagram

Cold box cross section

Length: 5.6...6 m;
Diameter: 3.6..3.8 m
**Natural Nelium concept**

- Corresponds to the neon-helium ratio in the air:
  
  Natural Nelium: \((\text{Ne:He}) \sim (3:1) + (3...8 \%) \text{H}_2\)

- Economically advantageous

- Current target composition: 60 % neon, 40 % helium → cheaper helium can be added

- Hydrogen presence in the mixture: good thermophysical properties

- Problem: instability of composition

**Crude nelium mixture production flow diagram**

![Crude nelium mixture production flow diagram](image)

![Thermal conductivity graph](image)
Secondments & Trainings & Dissemination events

- Secondment – Linde Kryotechnik, Pfungen, Switzerland (29.04.-14.06.2019)

- Scientific cooperation with ESR 15 – University of Stuttgart, Germany (18.03.-05.04.19)

- Cryogenics conference 2019, Prague, Czech Republic (07.04.-11.04.19)
Next steps

- Case study for the cycle design matching with the turbo-compressor design
- Part-load operation and buffer optimisation for the new cycle baseline
- Review of the cycle performance calculation
- Compander design
- Cool-down operation of the new cycle baseline
- Further study of the Natural Nelimium concept
- Participation in experiments on the neon-helium turbo-compressor test rig (University of Stuttgart)
- Secondment 2
Thank you for your attention!

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