Cryogenic System for the Ultra Cold Neutron Source (UCN Source) at the FRM II

Part 2: Main features, commissioning, operating, simulation and experience

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Outline of the presentation

- Main features
- Commissioning
- Operating
- Simulation
- Experience
Main features / Framework of the project

- High flux reactor FRM II of TU Munchen, production of ultra cold neutrons
  - Superthermal converter filled with deuterium and hydrogen in solid state
    - under construction
  - Cryogenic system to maintain converter temperature of 5K
    - UCN converter with a heat load of ~500W in steady state
    - Overall cooling system made of 3 separate cooling loops:
      - Two independent primary refrigeration circuits (compressors, ORS, CB1 and CB2) with a refrigeration capacity of 500W each
      - One CB3 cold box to feed the converter with 120g/s of supercritical Helium
  - CB1 and CB2 may operate simultaneously to boost the cooling power to CB3 from 500W to 1000W
Pre-requisite

- New Building starting from a green field

- Utilities
  - Cooling Water: Max flow rate for $\Delta T_{\text{max}}$ (15K) 15,2 m³/h
  - Power: Compressor 2 x 250 kW
  - Compressed air system
  - Fire alarm system
  - Ventilation plant (control of the temperature)
  - Oxygen detection system

- Installation of the equipment and all the pipes
Pre-commissioning

Equipment test
Operational test, electrical test, PID check, Leak test, conditioning

- 215 Lines tested
- 31 Safety Valves tested
- 31 Control Valves tested
- 141 Sensors tested
Machine Commissioning

Sub-system test
Basic automatic sequences test
Process and control optimization

- For Cold box 1 and Cold box 2:
  - Compressor start
  - Turbines installation and start
  - Vacuum start
  - Cool-down
- For Cold box 3:
  - Helium pump start
  - Cool-down
Machine Commissioning

Sub-system test
Basic automatic sequences test
Process and control optimization

- For Cold box 1 and Cold box 2:
  - Compressor start
  - Turbines installation and start
  - Vacuum group start
  - Cool-down
- For Cold box 3:
  - Helium pump start
  - Cool-down
Commissioning / Operating

Tested automatic sequences:

- For Cold box 1 and Cold box 2:
  - Compressor start and stop
  - Compressor emergency stop
  - Vacuum group start, stop and line pumping
  - Turbines start and stop
  - Cold box leak search
  - Cold box conditioning
  - Cold box depressurization
  - Cold box pressurization
  - Cold box drying
  - Cold box helium analysis
  - Cold box cool-down
  - Cold box voluntary stop
  - Cold box emergency stop
  - Cold box warm-up

- For Coldbox 3:
  - Vacuum group start and stop
  - Cold box cool-down
  - Cold box pressure management
  - Converter connection management
  - Cold box 1 and cold box 2 connection management
  - Cold box warm-up
Process Flow

Compressor

Exchanger E01

E02

E03

E04

E05

E06

E07

LP

299 K
14.5 bar

Vent

LN₂ storage

Turbine 1

Supercharger 1

Water Cooler 1

Turbine 2

Supercharger 2

Water Cooler 2

JT-Valve 1

JT-Valve 2

4.5 K / 1.35 bar

LHe

CB3

UCN Conv

Fig. 7 – Schematic of refrigeration process flow
Process Cold box cool-down

Cryogenic System for the UCN source at the FRM II
Simulation 1 “dummy converter” in the CB3

To be able to test and to commission the CB3 without the converter, a „converter-simulation“ was included into the design of the CB3

- The CB3 is build with a by-pass and a heater
- The heat load is simulated by the heater, regulating the temperature
Simulation 2 “dummy converter” outside the CB3

To be able to test and to commission the converter, a „dummy“ converter was created to avoid a damage on the original converter

- The „dummy-converter“ is designed to support more than 16bar pressure
- The heat load is simulated by a heater in side the „dummy-converter“
Recorded Performance CB1

Cryogenic System for the UCN source at the FRM II

Cold Box 3

- 3.35 bar
- 6.3 K
- 550 W

Cold Box 2

- 42.5 %
- 0.3 % FCV470
- 6.32 K
- 14.79 K
- 8.25 mbar

Cold Box 1

- 100.0 %
- 0.0 % FCV405
- 100.7 %
- 10.96 K
- 13.96 K
- 0.0 % FCV8012
- 0.0 % FCV802
- 0.0 % FCV807
- 0.0 % FCV808
- 0.0 % FCV809
- 28.0 %

He supply

From Converter

- 294.48 K
- 60.0 %
- 87.6 %
- 29.9 %

To Converter

- 12.30 K
- 24.34 K
- 20.82 K
- 20.89 K
- 25.19 K
- 14.8 %

Controller

- 42.5 %
- 50 %

Controller = 50 % EH086
Controller < 50 % FCV005

Graphs:
- Graph 666: 668
- Graph 669: 651
- Graph 720: 780

Vacuum start sequence

Parameters CB3
Recorded Performance CB1 & CB2

Cold Box 3

3.2 bar

6.2 K

1125 W

Cryogenic System for the UCN source at the FRM II

14.09.2018
Recorded Performance

<table>
<thead>
<tr>
<th>Test</th>
<th>Guaranteed cold power</th>
<th>Measured cold power</th>
<th>Test duration</th>
<th>Test conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB1 connected to CB3</td>
<td>500 W (+10%)</td>
<td>550 W</td>
<td>&gt; 12 h</td>
<td>TT804 = 5.5 K +/- 1 K: yes, 2.9 bar &lt; PT804 &lt; 3.8 bar: yes</td>
</tr>
<tr>
<td>CB2 connected to CB3</td>
<td>500 W (+9%)</td>
<td>545 W</td>
<td>&gt; 14 h</td>
<td>TT804 = 5.5 K +/- 1 K: yes, 2.9 bar &lt; PT804 &lt; 3.8 bar: yes</td>
</tr>
<tr>
<td>CB1 and CB2 connected to CB3</td>
<td>1 100 W (+2.3%)</td>
<td>1 125 W</td>
<td>50 min</td>
<td>TT804 = 5.5 K +/- 1 K: yes, 2.9 bar &lt; PT804 &lt; 3.8 bar: yes</td>
</tr>
</tbody>
</table>

1. COLD BOX 1 PERFORMANCE TEST

The cold box 1 was tested connecting to the cold box 3 during the months of May 26th 2016 and May 30th 2016. The test load was simulated by the sensors T804 measuring the temperature sensor TT804. The machine stayed at least 12 hours at stabilized conditions with:
- TT804: 5.5 K +/- 1 K, guaranteed value: 5.5 K
- TT804: 0.6 K +/- 0.1 K, stability condition: 0.6 K
- FP804: 0.03 bar +/- 0.01 bar, candidate condition: 0.03 bar

In the following pages of the document some test results of the performance test are available, performance data behavior (page 3), cold box 1 status (page 4) and cold box 2 status (page 5).

2. COLD BOX 2 PERFORMANCE TEST

The cold box 2 was tested connecting to the cold box 3 during the months of May 26th 2016 and May 30th 2016. The test load was simulated by the sensors T804 measuring the temperature sensor TT804. The machine stayed at least 14 hours at stabilized conditions with:
- TT804: 5.5 K +/- 1 K, guaranteed value: 5.5 K
- TT804: 0.6 K +/- 0.1 K, stability condition: 0.6 K
- FP804: 0.03 bar +/- 0.01 bar, candidate condition: 0.03 bar

In the following pages of the document some test results of the performance test are available, performance data behavior (page 3), cold box 2 status (page 4) and cold box 3 status (page 5).

3. COLD BOX 1 AND COLD BOX 2 PERFORMANCE TEST

The cold box 1 associated with the cold box 2 was tested connecting to the cold box 3 (last page). The test load was simulated by the sensors T804 measuring the temperature sensor TT804. The machine stayed at least 50 minutes at stabilized conditions with:
- TT804: 5.5 K +/- 1 K, guaranteed value: 5.5 K
- TT804: 0.6 K +/- 0.1 K, stability condition: 0.6 K
- FP804: 0.03 bar +/- 0.01 bar, candidate condition: 0.03 bar

In the following pages of the document some test results of the performance test are available, performance data behavior (page 3), cold box 1 status (page 4), cold box 2 status (page 5) and cold box 3 status (page 5).
Test for Reactortrip (Reactor schnell Abschaltung, RESA)

Test: Heat load falling instantly from 500 W to 0 W

The reactortrip was tested with succes
Experience and next step

Yes, we got the cooling power to reach 5K with a cold power of 500W and with a cold power of 1100W

The system was successfully tested using the „dummy-converter“

Next steps:
- Work on automatic warming up procedures
- Work on a „dummy“ converter, filled with deuterium and hydrogen in solid state
- Work on divers operating models (simulating reactor-scenarios / behaviours)
- Test of malfunction procedures

- In parallel: authorisation procedures for implementation of the UCN source in the FRM II
Thank for your attention