ESS Target Cryogenic System
European Cryogenic Days
CERN

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ESS Target Cryogenic Systems Overview

Target Moderator Cryoplant (TMCP) – Provides cooling to the H$_2$/He heat exchanger to remove heat from the hydrogen circuit. He circuit operates at approximately 15 K and 2.1 MPa.

Cryogenic Moderator System (CMS) – Cryogenic hydrogen system that circulates sub cooled liquid hydrogen to cold moderators, and removes heat through a heat exchanger to a cold helium circuit.

Cold Moderators – Cryogenic hydrogen moderators use sub cooled liquid hydrogen at 17 K and 1.1 MPa to reduce the energy of the neutrons.
Integrated TMCP/CMS/MR system

TMCP

Cold box

Compressors

Buffer tanks

CMS

H₂ transfer lines

Moderator Reflector

He transfer lines
ESS moderator & reflector system design

- Spallation Target
- Rotation Unit
- LH2 Transfer Lines
- Moderator & Reflector Plug
- LH2 Cryostat
ESS moderator & reflector unit design

Cold Butterfly moderator (LH$_2$)

Thermal moderator (water)

Be-Reflector/-vessel

LH$_2$ pipework

Vacuum chamber (extruded profile include 2 cooling chambers for thermal moderator water
Butterfly cold moderator provides significant increase in neutron brightness compared to ESS TDR design.
ESS cold Moderator heat input by neutrons

\[ h(x, y, z) = 2.287 + 33.9 \exp \left( -\frac{1}{2} \left( \frac{x - 5.34}{13} \right)^2 - \frac{1}{2} \left( \frac{\sqrt{y^2 + z^2} + 17.24}{18.18} \right)^2 \right) \]

\[ h(x, y, z) = -0.17317 + \frac{101.78613}{\left[ 1 + \left( \frac{x - 0.42345}{18.20385} \right)^2 \right] \left[ 1 + \left( \frac{\sqrt{y^2 + z^2} + 3.56612}{3.34324} \right)^2 \right]} \]

\[ \sum \text{upper cold Moderators} \approx 8.0 \text{ kW} \]
ESS cold Moderator fluid thermal dynamics
(temp temperature variation during 350 ms pulse)
ESS cold Moderator structural mechanics

Stress @15 bar / 20 K operation case

Stress @17 bar / 20 K design case S<=55 MPa

Stress @21.45 bar / 300 K test case S>55

Deformation (without Invar)

S=55MPa (RCC MRx)
Mounted Al-6061-T6 pieces bevor eBeam welding

Weld filler

First burst test with water / burst pressure 181 bar / design pressure 17 bar
Main task for the Cryogenic Moderator System.

The Target Station shall use para-H$_2$ material as cold moderator coolant such that the neutronic performance will sustain the required brightness while the technical risk will be residual thanks to the available experience using this material.

- Expected Heat load neutronic: 19.0kW incl. Contingency margin
- Expected Heat load static: 9.8kW
- Hydrogen content in system: 22kg liquid hydrogen
- Working Temperature: 17-20.5K
- Working pressure: 1.1MPa
- Design pressure: 1.7MPa
- Pressure drop: ~0.2MPa
- Expected mass flow: 1000 g/s
- Ortho-Para catalyist: Oxisorb placed in a by-pass line
- OP ratio: >99.5%
- In line measurement: Raman spectroscopy ahead and after moderator
- Pressure control: Active buffer, expansion vessel.
CMS Overview

Cryostat

Weight 3700kg
Ø: 1800mm
H: 2000mm

Pipes and components insulated with MLI
Small mean temperature variations can cause severe pressure fluctuations

\( \text{H}_2 \) at < 20 K almost incompressible

\( \text{H}_2 \) at > 35 K becomes compressible

-> buffer mitigates pressure variations
CMS Overview, heat exchanger 1 & 2

Heat exchanger 1:
- Aluminum plate fin exchanger
- Used to liquefy the hydrogen during fill and maintain temperature during operation

Heat exchanger 2:
- Fin tube exchanger
- To liquify $\text{GH}_2$ from buffer and main fill line during operation.
Hydrogen Pumps

Serial setup with 2 pumps

Each pump provides full mass flow but shares the pressure drop

If one pump fails the second pump will step up and compensate for the full pressure drop.

**Equipment spec pumps**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>$Q_{\text{max}}$: 1000g/s @17K</td>
</tr>
<tr>
<td>Working Temperature media</td>
<td>17-300K</td>
</tr>
<tr>
<td>Working pressure</td>
<td>1.1MPa</td>
</tr>
<tr>
<td>Set up</td>
<td>Serial connection, Both pumps at full flow, shared pressure drop</td>
</tr>
<tr>
<td>Fail mode</td>
<td>1 pump, 100% flow</td>
</tr>
<tr>
<td>Pressure drop estimated</td>
<td>$\Delta P$: 0.1/0.2MPa</td>
</tr>
<tr>
<td>Media</td>
<td>Gaseous, supercritical and liquid H$_2$</td>
</tr>
<tr>
<td>Control</td>
<td>Frequency Controlled motor</td>
</tr>
</tbody>
</table>
CMS Overview
connections to moderator plug

Manifold includes valves, instruments and raman probes.

Jumper connections with bayonet couplings inside the monolith.

- Vent line for hydrogen
- Connected to safety relief valves and manual release valves
- Purged with He/N₂
Unique attributes of the TMCP

- High **maximum** heat load: 30 kW at 15 K
- Wide **range** of dynamic heat loads: 5-30 kW
- 6 years from 1st protons on target to full power operation
- Multiple operating modes
  - Steady state – 15-100% of capacity
  - Transient – Cool down and warm up
  - Switching – Short term fast changes
- CMS requires narrow temperature range: 17-21 K
- High heat load and narrow temperature range means **high helium mass flow rate**
- Long cryogenic transfer lines results in high helium inventory - ~490 kg total
TMCP Design Drivers

Narrow operating range

Closed loop modified Brayton cycle

Large variation in heat load

H$_2$/He heat exchanger

0.00 MW
0.5 MW
1.43 MW
3.23 MW
5.01 MW

Beam off
Beam comm.
Phase 1
Phase 2
Phase 3

0.00 MW
0.5 MW
1.43 MW
3.23 MW
5.01 MW

Heat load (kW)

Static Heatload He Cryo TLs
Static Heatload H$_2$ Box + TLs
H$_2$ Circulators
Static Heatload Moderators
Neutronic heating

H$_2$/He heat exchanger

15 K
17 K
5 K max delta T
18.8 K
3.5 K max delta T

20 K
20.5 K
Helium
Hydrogen
TMCP Process Design Description

Operating modes

- Nominal design
- Low Power
- Beam trip

T-S diagram, nominal design

Temperature

Entropy

21.5 bar
313 K
1.1 kg/s

0.1 kg/s
5.2 bar
309 K

20.6 bar
20 K

21.2 bar
15 K

5.4 bar
14 K

CMS heat
Highlights

• Butterfly design successfully modeled, manufacturing process proven
• Butterfly design promises significant improvement in neutron brightness
• CMS Critical Design Review passed, detailed design on-going
• CMS buffer unique robust design, proof of concept testing planned
• CMS long lead items (pumps, heat exchanger) procurement cycle started
• TMCP contract award made May 2016
• Project on schedule
  – TMCP commissioning complete 4Q18
  – CMS installation complete 1Q19
  – Integrated testing 1-2Q19
Finis