Cryostats for superconducting magnets

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A typical magnet cryostat in the LHC

- ~1000 W of electrical power per 1 W extracted at 1.9 K: Extreme thermal insulation is a must!
- Thermal contraction of stainless steel ~3 mm/m length i.e. 45 mm over a 15 m dipole magnet; ~80 m over the whole LHC!
- Precise and stable alignment of large and heavy structures: tight fabrication tolerances
<table>
<thead>
<tr>
<th>Issue</th>
<th>Solution</th>
<th>Some requirements/specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection heat transfer</td>
<td>Vacuum (~10(^{-6}) mbar)</td>
<td>Leak tightness is critical, especially on large cryostats like the LHC. Qualification of welding procedures and welders. Material compatibility. Cleanliness.</td>
</tr>
<tr>
<td>Conduction heat transfer</td>
<td>Insulating support materials (ex. GFRE)</td>
<td>Stiffness and strength. Repeatability of material properties and dimensions. Layout taking into account thermal displacements.</td>
</tr>
<tr>
<td>Thermal radiation</td>
<td>Reflective surfaces (Multi-layer insulation)</td>
<td>Avoid openings. Low compactness. Proper assembly techniques to prevent thermal bridges. Film material and coating properties.</td>
</tr>
<tr>
<td>Thermodynamic efficiency</td>
<td>Intercept heat at intermediate temperatures (ex. thermal shield at 50-65 K)</td>
<td>High conductivity materials. Avoid poor thermal contacts.</td>
</tr>
</tbody>
</table>
For installation in 2019-2020: 11 T magnets

First $\text{Nb}_3\text{Sn}$ high field magnets in a particle accelerator will create space for installation of new collimators

- On-going integration study for trim current leads
- Specification drawings for bottom trays being prepared
- Drawings controlled
- Procurement started
- Prototype under fabrication
- QA documents being prepared
- Tooling design nearly finished

Overall integration length: 15660 mm
For installation in 2019-2020: Connection cryostats

New collimators installed in a location without magnets but new cryostats needed

Same bypass cryostat as for 11T in IR7

Two connection cryostat units
Detailed calculations and 3D modeling on-going

Main challenge: alignment and stability of the beam lines w.r.t. interconnect forces

- Details on alignment and stability of beam lines being studied by simulations and tests

Overall integration length: 12774.7 mm
For installation in 2024-2025: Insertion regions

$\text{Nb}_3\text{Sn}$ quadrupoles, separation dipoles and others

- Larger magnet diameters but cryostat of same diameter because of tunnel size restrictions: compact design
- New support system
- Complex interconnect and pipework
- Under design
For installation in 2024-2025: Cryostats for interfaces with cold powering

- Electrical connection between the circuits in gaseous helium and the superconducting magnet circuits in superfluid helium
- Prototype and tooling by Q1 2018
- 8 unis + 2 spares for production in 2019-2020

+ Supporting structure
+ Safety devices
+ Instrumentation
+ Tooling
+ Expansion joints
In a few numbers

- 77 cryostat units | 70 procured by CERN, incl. prototypes and spares
- Diameter ~1 m
- Unit lengths vary from 2 m up to 15 m
- Roughly 500 m of new cryostats to be installed in the LHC
- Carbon steel, stainless steel, aluminium, glass fiber composites…
- Production from now until 2025

![Assembly schedule at CERN](image-url)
Strategy for construction

- Design done at CERN (internal design office with service contractor)
- Procurement of components in industry, mostly as “build-to-print” supplies according to CERN drawings and detailed specifications
- Assembly at CERN with on-site support of industrial contractors (ex.: mechanical assembly, welding, quality control)
Vacuum vessels

- Cylindrical sections in carbon steel (certified for pressure applications at -50°C) with flanges in stainless steel
- Precisely machined interfaces (large milling machines needed)
- Qualified welders and welding procedures
- Leak detection, welding NDT, 3D metrology
- Full traceability
Multi-layer insulation

- Reflective sheets made from polyester film with aluminium thin coating on both sides
- Supplied in blankets of 10 or 15 reflective layers interleaved with insulating spacer layers made from polyester net
- Blankets joined with Velcro® tape
- Shape and size of the blankets to be designed by the manufacturer
- About 50’000 m² of reflective layer!
Thermal shields

- Aluminium extrusions or roled sheets as structural elements
- Up to 14 m long
- Precise machining of support interfaces and extremities
- Aluminium to stainless steel transitions
- Leak tight aluminium welds
Cold supports

- Designed for stiffness and strength with minimum heat load
- **Glass fibre** reinforced epoxy
- Tight control of packing factor
- Equal and repeatable thermal contraction
- Finish machining after moulding
Expansion joints

- Compensation for thermal contraction during cooldown
- Reliability, leak tightness over the machine lifetime
- From vacuum to 20 bar
- EJMA, EN 13445
- Strict material specifications
- Full traceability of materials, manufacturing and QC
- ~500 units
Piping and ancilliaries

- Required inside most cryostats for helium distribution and routing of superconducting cables
- Pressurised up to 20 bar
- EN 13480
- Qualified welders and welding procedures
- Extensive welding QC
Cold mass for connection cryostats

- Used in cold parts of the accelerator without magnets, to route cryogenic services and superconducting cables
- Precise alignment
- Uniformity of temperature
- Pressure vessel 20 bar
- EN 13458, EN 13445
- Stainless steel with cobalt content < 0.10%
- 4 units plus 2 spares
- Assembly in 2018
## Upcoming procurement contracts (main items)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Milestones</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass proto vacuum vessel</td>
<td>1 unit</td>
<td>Order issued Oct 2016&lt;br&gt;Delivery April 2017</td>
<td>Contract adjudication</td>
</tr>
<tr>
<td>11T and Connection Cryostat series vacuum vessels</td>
<td>13 + 6 optional</td>
<td>Tendering process started Sep 2016&lt;br&gt;Finance committee and order issued June 2017&lt;br&gt;Delivery of first unit Nov 2017&lt;br&gt;Delivery of last unit end 2018</td>
<td>Market survey docs under preparation</td>
</tr>
<tr>
<td>Bypass series vacuum vessels</td>
<td>6 units</td>
<td>Tendering process starts Oct 2016&lt;br&gt;Order issued Jan 2017&lt;br&gt;Delivery of first unit June 2017&lt;br&gt;Delivery of last unit June 2018</td>
<td>Preparation of PE docs</td>
</tr>
<tr>
<td>Q1/3 proto, Q2 proto 1, Q2 proto 2</td>
<td>3 units + 1 optional</td>
<td>Start procurement procedure Mar 2017&lt;br&gt;Order issued Mar 2018&lt;br&gt;Delivery first unit Sep 2018&lt;br&gt;Delivery last unit Aug 2019</td>
<td>Planning</td>
</tr>
<tr>
<td>Q4 and Q10</td>
<td>8 + 2 optional</td>
<td>Start procurement procedure June 2017&lt;br&gt;Order issued Jun 2018&lt;br&gt;Delivery first unit Dec 2018&lt;br&gt;Delivery last unit Dec 2019</td>
<td>Planning</td>
</tr>
<tr>
<td>Q1/3 series, Q2 series, all CP, all D2</td>
<td></td>
<td>Start procurement procedure June 2018&lt;br&gt;Order issued May 2019&lt;br&gt;Delivery first unit Nov 2019&lt;br&gt;Delivery last unit Dec 2022</td>
<td>Planning</td>
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Thank you for your attention!