Cryomodule options for the ERL of the LHeC, FCC_eh (and Perle)

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Cryomodules

The main functions of a cryomodule

• Give the cryogenic environment for the cold mass, i.e. the cavity and/or magnet (only cavity in the ERL case): perform the cryofluids distribution
  • Helium (LHe) and/or Nitrogen (LN)
  • Handle the liquid and vapor phase of the cryofluids
    ➢ Cavity operating temperature: 4K (atm. Pressure) or 2K (~30 mbar)
    ➢ Thermal shield could be actively cooled by cold He gaz or LN
    ➢ Power coupler might required an active cooling
  • Vacuum
    • Perform the thermal insulation against all heat transfer from room temperature to the cold mass:
      • limit losses by conduction, convection or radiation
    • Supporting and positioning of the components:
      • Structural support for the cold mass
      • Precise alignment of the cavities with respect to the beam axis and keep the alignment over the thermal cycles
• Provide magnetic shielding to the cavities
LHeC CDR:

- Number of cryomodules: 2 x 60
- Number of cavities per cryomodule: 8 (with $Q_0 \ 2.5 \times 10^{10}$)
- Number of refrigerators: 8 (one per 250m of linac)
- Operating temperature: 2 K
- Total cryogenic power @ 4.5 K: 80 kW (no uncertainties factors taken)
  (largely dominated by dynamic load)
Several cryomodule requirements could be listed for ERLs, and some of them are very challenging. They are of two types:

1. The classical challenges imposed by SRF:
   - Limit as much as possible heat transfer
   - Take into account all mechanical constraints
   - Design allowing an easy assembly procedure
   - ... and as usual, optimize for cost!

2. The additional constraints coming from the cavities operated in the ERL mode and CW/high current operation mode:
   - High CW cryo loads
   - Low level of vibration, and damping of them
   - Excellent magnetic shielding (high Qo)
   - Accurate cavity alignment
The classical challenges in designing SRF cryomodules
1. Limit as much as possible heat transfer
   • Cold mass (spoke cavities) needs to operate at 2K.
   And 1 W dissipated @ 2K costs ~700 W of electrical power to maintain @ 2K !
   -> optimization of running cost for the accelerator
   • The 3 heat transfer mechanisms:
     - Use of material exhibiting poor thermal conductivity
     - Use small sections for the interface rods
     - Use thermal intercepts
     - Operate in vacuum !
     - Use thermal shields at intermediate temperature
     - Use low emissivity materials
     - Use multi-layer insulation
2. Mechanical constraints

- Isolation vacuum:
  The cryomodule external vessel has to sustain external pressure

- Thermal gradients:
  Thermal contractions induces mechanical constraints

- Gravity: component mass
  A fully equipped cavity can weight > 250 Kgs

They all have an impact on the alignment and component stability

- Use material with low thermal contraction coefficient (ex: TiA6V, composite materials)
- Use geometrical “tricks” to add flexibility (bellows, bended tubes,...)
- Use of materials with high elastic limit to sustain the forces

Temperature map in the ESS spoke cryomodule
(P. Duchesne, IPNO)
3. Assembly and maintenance constraints

• The cavity string is prepared and sealed in a clean room
  ➢ *Reduce* as much as possible the amount of material inside clean room for improved contamination control
  ➢ *Optimize* the number of assembly operations inside the clean room

• Design a cryomodule which can be “easily” assembled and maintained
  ➢ *Optimize* parts and components access
  ➢ During all assembly steps, maintain or control/monitor alignment

4. Cost constraint!

➢ *Obvious*: optimize the cryomodule component cost but also the required amount of manpower to assemble
➢ *Also think about the cost of assembly tooling*
Comparison between XFEL cavity performances achieved in VT vs CM

Accelerating gradient
- degraded by 3% in average
  (modulated by administrative limit at 31 MV/m)

Quality factor
- no clear trend (but difficult to measure on cryomodule)
Specific challenges of ERLs cryomodules
High cryo loads generated by the CW and high current operation mode

• A large number of significant dynamic heat loads in an operation mode where dynamic loads are >> static loads
  • Cavity
  • High order Mode (HOM) couplers
  • CW input couplers

• Design question/optimization points to find for cryostat/cryoplant: cryo load
  • Thermal shield temperature optimum
  • How to efficiently extract HOM power, at what T°
  • Cryo load varies a lot between RF on/off: cryoplant (and cryogenic distribution) flexibility is required
  • Cavity optimum operating temperature: cost vs cavity performances vs helium bath stability
  • Keeping the cavity high Qo -> cryostat design optimized for magnetic shielding
  • How to cool the cavities (series/parallel) in order to insure “magnetic hygiene” (is this really an issue for high Qo @ 802 MHz ?)
**Specific constraints in ERLs cryomodules**

- Design question/optimization points to find for cryostat: vibrations management
  - How to insure low mechanical vibrations levels – what is the source?
  - How to damp vibrations to ease cavity control

- Design question/optimization points to find for cryostat: magnetic shielding
  (required for high Qo, required cavities submitted to less than a few mG)
  - What magnetic material, at what temperature? -> data available now
  - How many layers of magnetic shield?
  - Active shielding could help?
  - Very few worldwide experience of magnetic shielding requirements for high Qo at frequencies in the 500 – 800 MHz range
Design options for ERL cryomodules
Cryomodule type #1: SNS or ESS like

- Developed first by SNS and then adapted and improved for ESS
- Specific characteristics:
  - Cold mass supported by the “spaceframe”: an assembly tooling remaining in the cryostat
  - Side loading
Cryomodule type #2: ILC or XFEL-like

• Developed for Flash, XFEL (and LCLS-II) and ILC

• Specific characteristics:
  • Long cryostat (8 cavities)
  • Continuous cryogenic line (reduced number of cold/warm transition)
  • Gaz return pipe as the mechanical supporting system for the cavity string
Cryomodule type #3: SPL-like

• Developed within the SPL project framework by IPNO and CERN
• Specific characteristics:
  • Full length top-lid closure
  • Cold mass supported by power coupler
SPL prototype short cryomodule to be use as the prototype PERLE cryomodule?
POTENTIAL REUSE OF THE SPL/HG CRYOMODULE DESIGN AND COMPONENTS

For more details about SPL (HG) cryomodule: presentation of Luca DASSA. PERLE workshop, Daresbury on January 15th, 2018.

Design of the cryomodule performed by IPNO and updated by CERN.

Vacuum vessel and most of cryogenic lines delivered.

CAN THIS DESIGN AND THESE COMPONENTS BE REUSED FOR PERLE @ ORSAY?
## MAIN DIMENSIONAL CHARACTERISTICS OF THE CAVITIES

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>SPL (704MHz)</th>
<th>PERLE / JLAB (802MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupler to coupler length (mm)</td>
<td>1490,5</td>
<td>-</td>
</tr>
<tr>
<td>Length flange to flange (mm)</td>
<td>1397,3</td>
<td>1292,5</td>
</tr>
<tr>
<td>Coupler to flange dimension (mm)</td>
<td>116,4</td>
<td>96,7</td>
</tr>
<tr>
<td>Cells external diameter (mm)</td>
<td>386,5</td>
<td>335</td>
</tr>
<tr>
<td>Beam port internal diameter (mm)</td>
<td>129,8 / 139,8 (coupler side)</td>
<td>130</td>
</tr>
<tr>
<td>Flanges internal diameter (mm)</td>
<td>79,7 (CF100)</td>
<td>130 (CF160)</td>
</tr>
<tr>
<td>Vacuum valve diameter</td>
<td>CF63</td>
<td>tbd</td>
</tr>
<tr>
<td>Coupler internal diameter (mm)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Coupler flange</td>
<td>CF100</td>
<td>CF100</td>
</tr>
<tr>
<td>Beam axis to ext. coupler flange</td>
<td>403</td>
<td>tbd</td>
</tr>
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</table>

### SIMILAR FEATURES
The cavities are supported and positioned directly by their coupler flange. The opposite side (with respect to the coupler) of each cavity is supported and positioned by means of a spherical joint fixed on the next cavity.

Displacement of the cavity string alone (weight only)

Max: 0.12 mm

Cavity string equipped with magnetic shield, CTS, cryogenic lines and thermal shield

Insertion of the complete assembly inside the vacuum vessel

Closing of the top lid and of the beam ports

Courtesy of P DUTHIL / S ROUSSELOT (IPNO)
BEAM VACUUM VALVES

Maximum valve height: 180mm (from beam axis)

NEED OF A "TWO STAGES" SOLUTION TO USE AN ALL METAL GATE VALVE

CF63 "Vatterfly" valve with manual actuator
VAT Ref. 20336-CE14

All metal gate valves (commonly used)
< 1.10-10 mbar.l/s
< 1.10-10 mbar

Height of all metal gate valves (VAT series 48) with pneumatic actuator:
CF40: 312mm
CF63: 527mm

Limited space for screwing on each side (but OK)

Actuator to remove
300K thermalization for valve and flange
High T° gradient between 50 and 300K
HOM EXTRACTION

- How many extraction ports (interferences with CTS)?
- Which power (W, tens of W, more)?
- What kind of damper (waveguide, loop coupling)?
- Active helium cooling or thermalization by copper braids
- What kind of RF line to the external load (cable sufficient, which kind of connector)?
- Intermediate thermalization of the cables
- External cooled RF loads

POTENTIALLY THE MAIN ISSUE DUE TO THE LACK OF SPACE
POTENTIAL REUSE OF THE SPL/HG CRYOMODULE DESIGN AND COMPONENTS

- Vacuum vessel could be reused without refurbishing
- Cryogenic lines to be adapted?
- Thermal and magnetic shields designed but not yet purchased. They can be modified.

- The internal space is almost full
- Risk of interference between CTS and HOM dampers
- The reuse of the cryomodule will depend on the number and the type of the HOM dampers
Any question?