SUPERCONDUCTING CAVITIES AND CRYOMODULES FOR PROTON AND DEUTERON LINACS

G. DEVANZ

CEA-Irfu, Saclay
OUTLINE

• ESS
  • SRF linac
  • Spoke
  • Ellipticals
    • Cavities
    • cryomodules
    • Power couplers
  • Future tests
• SPIRAL2
  • Test status
• IFMIF-LIPAc
  • Cryomodule
  • HWR
  • Power couplers
  • Test stand
See M. Eshraqi THIOA01

<table>
<thead>
<tr>
<th>Beam power (MW)</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam current (mA)</td>
<td>62.5</td>
</tr>
<tr>
<td>Linac energy (GeV)</td>
<td>2</td>
</tr>
<tr>
<td>Beam pulse length (ms)</td>
<td>2.86</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Num. of CMs</th>
<th>Num. of cavities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoke</td>
<td>13</td>
</tr>
<tr>
<td>6-cell medium β</td>
<td>9</td>
</tr>
<tr>
<td>5-cell high β</td>
<td>21</td>
</tr>
</tbody>
</table>
**Power Coupler**

- Ceramic disk, 100 mm diameter
- 400 kW peak power
- Antenna & window water cooling
- Outer conductor cooled with Lhe
- Doorknob transition from coaxial to ½ height WR2300 waveguide
- 4 prototypes under fabrication (delivery in early October 2014)

**Double Spoke SRF Cavities**

- Double spoke cavity (3-gaps), 352.2 MHz, β=0.50
- Goal: $E_{acc} = 9 \text{ MV/m}$ [$B_p = 72 \text{ mT}; E_p = 39 \text{ MV/m}$]
- 4 mm (nominal) Niobium thickness
- Titanium Helium tank, Ti stiffeners
- Lorentz detuning coeff.: $-4.4 \text{ Hz/(MV/m)^2}$
- Tuning sentivity $\Delta f/\Delta z = 128 \text{ kHz/mm}$
- 3 prototypes under fabrication (delivery sept & oct 2014)

**Cold tuning system**

- Slow tuner (stepper motor):
  - Max tuner stroke: 1.28 mm
  - Max tuning range: 170 kHz
  - Tuning resolution: 1.14 Hz
- Fast tuning by 2 piezos actuators
  - Noliac 50x10x10 or PI 36x10x10 mm
  - Applied voltage up to +/- 120 V
  - Estimated tuning range: ~ 1 kHz
- 2 prototypes already fabricated
### 704.42 MHz Elliptical Cavities

<table>
<thead>
<tr>
<th></th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical beta</td>
<td>0.67</td>
<td>0.86</td>
</tr>
<tr>
<td>Number of cells</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>1259</td>
<td>1316</td>
</tr>
<tr>
<td>Nominal Accelerating gradient (MV/m)</td>
<td>16.7</td>
<td>19.9</td>
</tr>
<tr>
<td>Nominal Accelerating Voltage (MV)</td>
<td>14.3</td>
<td>18.2</td>
</tr>
<tr>
<td>$Q_0$ at nominal gradient</td>
<td>&gt; 5e9</td>
<td></td>
</tr>
<tr>
<td>Cavity dynamic heat load (W)</td>
<td>4.9</td>
<td>6.5</td>
</tr>
<tr>
<td>$Q_{ext}$</td>
<td>7.5 $10^5$</td>
<td>7.6 $10^5$</td>
</tr>
<tr>
<td>Iris diameter (mm)</td>
<td>94</td>
<td>120</td>
</tr>
<tr>
<td>Cell to cell coupling k (%)</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td>$\pi$ and 5$\pi$/6 (or 4$\pi$/5) mode separation (MHz)</td>
<td>0.53</td>
<td>1.2</td>
</tr>
<tr>
<td>$E_{pk}/E_{acc}$</td>
<td>2.35</td>
<td>2.2</td>
</tr>
<tr>
<td>$B_{pk}/E_{acc}$ (mT/(MV/m))</td>
<td>4.78</td>
<td>4.3</td>
</tr>
<tr>
<td>Maximum. $r/Q$ ($\Omega$)</td>
<td>397</td>
<td>477</td>
</tr>
<tr>
<td>Optimum $\beta$</td>
<td>0.705</td>
<td>0.92</td>
</tr>
<tr>
<td>$G$ ($\Omega$)</td>
<td>197</td>
<td>241</td>
</tr>
<tr>
<td>Static KL (Hz/(MV/m)$^2$) with tuner</td>
<td>-2</td>
<td>-1</td>
</tr>
</tbody>
</table>

- No HOM couplers
- Cold magnetic shield over the He jacket (target 1.4 $\mu$T)
- Use as far as possible tesla technology material (Ti tank, Al gaskets)
HIGH BETA PROTOTYPES

FNP 1-1-2.4 etching performed on BCP/EP cabinet

Field flatness: 92%

Base performance
NO heat treatment, NO baking yet

• T = 2.0K
• No quench: limited by cryostat cooling

Prototype #2 is ready for vertical test

Bpk = 105 mT
Epk = 54 MV/m
Updated design

- Simpler 40 K thermal shield
- Cryogenics and PED: lower pressure drop from He vessel to safety devices
• Most critical « vessel » is the Helium volume between cavity and helium jacket (many welds, exotic materials)

• Example : XFEL cavities follow Cat. IV related verification units (B1,B,F,G modules)

  → If possible, favor lowest categories

• ESS spoke and ellipticals CM have been designed in order to have PS . V < 50 for the Helium vessel (Art. 3 § 3)

  → Design has to follow « Sound engineering practice »

PS = « Maximum Allowable Pressure », relative to atmospheric pressure (barg)
New design of the doorknob waveguide transition including a HV bias capacitor with RF trap

- Saclay HIPPI power coupler (KEK-type window) tested to 1.2 MW, 10% duty factor
- ESS requirements 1.1 MW, 4% duty factor
- RF test stand is being refurbished for pulse length of 3 ms
- Plan is to process 4 FPCs for the cryomodule, with 2 spares

Test of the HIPPI power coupler a b=0.5 5-cell cavity at 1.8 K, full reflection, horizontal cryostat
TEST PLANS

Spoke :

- RF power test of the IPNO cryomodule at Upsala University

Ellipticals :

- 6 medium $\beta$ cavities: manufacturing, preparation and vertical test
- 4 power couplers + 2 spares: manufacturing and conditioning
- Manufacturing of the cryomodule components
- Assembly of the Medium $\beta$ cavities technical demonstrator (MECCTD)
- RF power test at Saclay in CM test bunker

- Repeat with high $\beta$ cavities technical demonstrator (HECCTD) re-using the MECCTD components
RIB facility installed in GANIL Caen

- Deuterons (5 mA) and ions up to q/A=1/6
- Temperature: 4.5 K
- Frequency: 88 MHz
- $E_{\text{acc max}}$: 6.5 MV/m

12 Low beta CMs
$12 \beta = 0.07$ QWR
CEA-IRFU Saclay

7 high beta CMs
$14 \beta = 0.12$ QWR
IPN Orsay

28 power couplers
LPSC Grenoble
QWR AND CM PERFORMANCE

- All cavities above specifications
- 8/12 low $\beta$ CMs tested
- Test transport Saclay-Ganil-Saclay
- 5/7 high $\beta$ CMs tested

Test transport Saclay-Ganil-Saclay: No performance degradation

MORE on cryomodule performance:
P.-E. Bernaudin
THIOB03 next session
Objective of the International Fusion Material Irradiation Facility: characterization of materials with intense neutrons flux ($10^{17}$ n/s) for the future Fusion Reactor DEMO (~150 dpa)

The Engineering Validation and Engineering Design Activities (EVEDA) aims to validate the key technologies

**Linear IFMIF Prototype Accelerator** to be tested in Rokkasho – Japan (low energy part, 125 mA of $D^+$ CW beam)

The LIPAc cryomodule is developped by CEA with Ciemat (SC solenoïd package, coupler processing)
Contains 8 HWR + 8 SC solenoid packages (solenoid, steerers, BPM)
HWR and SC solenoids positioning:
Support Frame + Xfel type C-rollers + invar rods
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>175</td>
<td>MHz</td>
</tr>
<tr>
<td>Maximum $r/Q$</td>
<td>150</td>
<td>Ohm</td>
</tr>
<tr>
<td>Optimum beta</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Design beta</td>
<td>0.094</td>
<td></td>
</tr>
<tr>
<td>$r/Q$ @ design beta</td>
<td>140</td>
<td>Ohm</td>
</tr>
<tr>
<td>Epk/Eacc</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Bpk/Eacc</td>
<td>11</td>
<td>mT/(MV/m)</td>
</tr>
<tr>
<td>Nominal Eacc</td>
<td>4.5</td>
<td>MV/m</td>
</tr>
<tr>
<td>Nominal Qo</td>
<td>$5 \times 10^8$</td>
<td></td>
</tr>
</tbody>
</table>

After plunger tuner removal prototype P02 performance exceed specifications.

The original cavity design includes a superconducting plunger tuner.
NEW DESIGN WITH COMPRESSION TUNER

- Disengagement system required for thermal transients
- Displacement of each beam port is 0.3 mm (8000 N compressive force) → detuning of -78 kHz

Start of production of HWR linked to licensing in the framework of Japanese High Pressure Gas Safety Law. Mainly issues with material and welds employed Nb, Ti, NbTi
Design: 200 kW CW @ 175 MHz
Maximum forward power on LIPAc: 70 kW

Conditioning at Ciemat:
• A pair of prototypes assembled in clean room on a test box
• Baking 170°C 100 hr
• Travelling wave up to 100kW CW: done
• Standing wave up to 100kW CW: done for most critical positions of Epk
→ couplers design is validated for the LIPAc
Recent decision to test the full cavity package (HWR + power coupler + tuner) before the LIPAc cryomodule assembly

Current horizontal test cryostat Cryholab too small
Built a satellite as a simple top-loading cryostat
  • Uses internal cryholab cryogenic circuits and components
  • Includes its thermal shield and cryo safety devices
  • Equipped with a magnetic shield
  • HWR, coupler and tuner are tested in CM position
  • RF power required 30 kW CW
New ISO7+ISO5 clean room required for ESS cavity string assembly, will be used for SPIRAL2 last CM assembly, and ifmif HWR preparation.
Thank you for your attention