Thomas Jefferson National Accelerator Facility

UPGRADE AND HIGH CURRENT CAVITY DEVELOPMENTS

Joseph Preble
for the Jefferson Lab
Institute of SRF Science and Technology
And Mechanical Engineering Group
Outline

• Jefferson Lab CEBAF Upgrade
  – Cryomodule/Cavity Requirements
  – Cavity Solution
  – Cavity Performance
  – HOM Issues
  – Future Activities

• Jefferson Lab High Current Program
  – Background
  – Cryomodule Concept
  – Cavity and Critical Component Status
  – Future Activities
12 GeV CEBAF

Two 1.1 GV linacs

Upgrade magnets and power supplies

Add 5 cryomodules

20 cryomodules

Add arc

Add 5 cryomodules

20 cryomodules

Enhanced capabilities in existing Halls

Lower pass beam energies (2.2, 4.4, 6.6 GeV) still available
Requirements Overview

- Add 1 GV, 0.5 GV per Linac
- 1497 MHz CW
- 10 Cryomodules (CM), 100 MV each
- CM has 5.6 m active length, 8 ea 7 cell cavities
- $E_{acc} \sim 19 \text{ MV/m includes operational overhead}$
- 400 $\mu$A injected current (up to 6 passes)
## Parameter List

<table>
<thead>
<tr>
<th><strong>Cryomodule</strong></th>
<th><strong>Cavity</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total active length</td>
<td>5.6 m</td>
</tr>
<tr>
<td>Voltage</td>
<td>108 MV</td>
</tr>
<tr>
<td>2 K heat load</td>
<td>≤300 W</td>
</tr>
<tr>
<td>50 K heat load</td>
<td>≤300 W</td>
</tr>
<tr>
<td>Cryomodule length</td>
<td>~8.5 m</td>
</tr>
<tr>
<td>Frequency</td>
<td>1497 MHz</td>
</tr>
<tr>
<td>Cavity active length</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Geometry Factor</td>
<td>280 Ω</td>
</tr>
<tr>
<td>Ep/Eacc</td>
<td>2.17</td>
</tr>
<tr>
<td>Hp/Eacc</td>
<td>3.74 mT/(MV/m)</td>
</tr>
<tr>
<td>Gradient</td>
<td>19.2 MV/m</td>
</tr>
<tr>
<td>Qext Fundamental Power Coupler (FPC)</td>
<td>3.2 * 10^7</td>
</tr>
<tr>
<td>FPC power rating</td>
<td>13 kW</td>
</tr>
<tr>
<td>Dipole mode damping</td>
<td>&lt; 1 * 10^10 Ω/m</td>
</tr>
</tbody>
</table>
Cavity Performance
Upgrade Baseline Plan

- C100 Cavities with standard BCP processing meet project requirements
Cavity Performance with electro-polishing processing

- Aggressive BCP polishing had degraded $E_{acc}$ and $Q_0$ performance
- EP processing recovers and improves performance
Cavity Performance with electro-polishing, promising results

- Light EP processing improves $E_{\text{acc}}$ and $Q_0$ performance after normal BCP processing
HOMs

• Requirement for injected beam current was increased, 100 $\rightarrow$ 400 $\mu$A

• Dipole mode damping $< 1 \times 10^{10}$ $\Omega$/m

• All requirements are met by existing design but …..

• Concern over cavity performance prompted extensive simulations and measurements

• End effects (including cavity to cavity) are critical for coupling at the beamline HOM couplers

• FPC coupling and HOM damping in the warm waveguide network is required
C100 cavity dipole impedance

Dipole shunt impedances for C100-1 and C100-2 respectively as derived from measured Ql values.

Order of magnitude margin for more stringent requirements
C100 Cavity Future

- Continue to investigate EP as an alternative to BCP (possibly a combination of both, BCP with a final EP)
- We will make a few, ~8, more C100 cavities in house
- Production order for 86 cavities has been placed
- Start receiving cavities next spring
- Finalize production processes and documentation before the cavities start to arrive
High Current Program
High Current Program

- JLAB has been in the business of FELs and ERLs for a long time using CW SRF linacs
- Existing Jefferson Lab designs are ok for ~ 10 mA and are in routine use at the existing JLAB FEL
- Beam current requirements have gone from ~ 1 mA to ~10 mA to ~100 mA and talk of ~1 A
- Design and fabrication of 1 Amp and 100 mA cavities, 748.5 and 1497 MHz respectively, are complete (748.5 scaled to 1497 MHz)
- Conceptual designs for 1 A and 100 mA cryomodules is complete and design work continues on the 100 mA cryomodule
High Current Application, 1 Example

High-average power ERL's face many challenges on the “current” frontier. Some similar to storage ring e+e- colliders, e.g. HOM damping, RF power.

Typical “industrial-strength” FEL:
- \( \sim 100 \text{MeV} \) beam energy,
- \( \sim 100 \text{kW} \)+ optical power
- \( \sim 100 \text{mA} \)+ beam current
- Compact layout (e.g. Dave Douglas)
- High real-estate gradient
- CW
- Low cryogenic load
  - Low wall losses
  - Warm HOM loads

Jefferson Lab
1 Amp Cryomodule

- **Requirements**
  - Voltage: 100-120 MV
  - Length: ~10m
  - Frequency: 750 MHz
  - Beam Aperture: >3” (76.2mm)
  - BBU Threshold: >1A
  - HOM Q’s: <10^4
  - Beam power: 0-1MW

- **Other concerns:**
  - Low cryogenic losses
  - Maintainability, flexibility, cost.
1 Amp Cryomodule Concept
6 each, 5 cell cavities

- Water cooled HOM loads placed at ambient temperature
- Niobium extension
- 50 K heat station to intercept heat leak

Diagram details:
- Spaceframe
- Thermal Shield
- HOM Waveguides
- Cavity / Helium Vessel / FPC / Warm Window
- Top Hat Bellows
- Return Header
1 Amp Cryomodule Concept

6 cavity string

Spaceframe / Thermal Shield Assembly
1 Amp CM Cryogenic Heat Load

- Dynamic Heat Load @ 2K ~ 400 W
  - Cavity Dissipation = 55 W per cavity
    - $E_{acc} = 16.7$ MV/m, $Q_0=8E9$, $R/Q = 636$
  - HOM Dissipation ~ 8 W per cavity
    - 4 kW Power, 1.5 GHz
- Dynamic Heat Load @ 50 K ~ 190 W
  - Due to heat-stationed HOM waveguides
  - FPC waveguides are gas-cooled
    - 200 kW operation requires 4x SNS-flow per coupler
      - 0.15 g/sec/coupler
- Totals with Static Heat Load
  - 2K ~455 W
  - 50K ~550 W
High Current Cavities

• Design considerations
  – Keep trapped modes away from beam resonances avoiding extremely large HOM power
  – Good HOM damping
  – Avoid multipacting barriers

Prototype 1497 MHz cavity with endgroups

1497 MHz 5 cell HC (100 mA) cavity
Cavity design

• Cell shape
  – Comparison with other SRF projects
  – JLAB uses a single geometry or center and end cells, end cells trimmed differently
Cavity design

• Multipacting simulation using FishPact
Cavity Performance

- Extensive bench testing of Copper and Niobium single cell and multi cell cavities

Bead-pull HOM measurement setup
Cavity Performance

- 1497 MHz Vertical Test Data

![Graph showing cavity performance data with Q0 on the y-axis and Eacc (MV/m) on the x-axis. The graph includes data points for cavity #1 and cavity #2, with labels for quench limited and power limited. The goal is indicated with an arrow.]
Components

• HOM Waveguide Coupler
• Combination HOM/FPC Waveguide Coupler
Components

- HOM Load, 4 kW
- RF planar window, M. Stirbet THPPO056

High power load design and simulation results
100 mA Cryomodule Design

- Use existing 1497 MHZ cavities
- Use existing horizontal test bed cryostat
- Complete designs of “critical” components, FPC, HOM couplers and loads, RF window

Conceptual design of a cavity-pair cryomodule
100 mA Cryomodule Plans

• Complete design, fabrication, and assembly
• Tests in FY10
  – Acceptance testing in the Cryomodule Test Facility
  – Beam tests in the FEL
High Current Program

- Actively prototyping and testing critical components
  - Cavities
  - RF couplers, FPC and HOM
  - RF windows
  - HOM loads
- Cryomodule designs going forward existing components as much as possible
- Beam test in FY10
Summary

- 12 GeV Upgrade cavity work is in good shape and the order for 86 cavities has been placed
- Work continues on improving processes for best cavity performance
- High current program at Jefferson Lab in alive and well
- Design, prototype, and testing of components is ongoing
- Design work for a beam test cryomodule has started
- Beam test is planned for FY10