Measurement and Control of Microphonics in High Loaded-Q Superconducting RF Cavities (THP66)

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Outline

• SRF cavities for the Rare Isotope Accelerator (RIA)
• Beam loading & rf requirements
• Prototype elliptical cryomodule
  • THP70
  • Collaboration with JLAB
• Microphonics measurements
• Adaptive feedforward cancellation of sinusoidal disturbances
  • TUP76
RIA SRF Cavities

Legnaro

MSU

$\beta_{\text{opt}} = 0.041$
80.5 MHz

$\beta_{\text{opt}} = 0.085$
80.5 MHz

$\beta_{\text{opt}} = 0.285$
322 MHz

MSU

MSU/JLAB

$\beta_{\text{opt}} = 0.49$
805 MHz

SNS

$\beta_{\text{opt}} = 0.63$
805 MHz

$\beta_{\text{opt}} = 0.83$
805 MHz

SNS
Beam loading & rf requirements

- Design beam for RIA driver linac
  - 400 kW, 400 MeV/u $^{238}\text{U}^{88,89,90+}$
  - 0.37 mA

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<thead>
<tr>
<th>Type</th>
<th>6-cell</th>
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<tbody>
<tr>
<td>$\beta_g$</td>
<td>0.47</td>
<td>0.61</td>
<td>0.81</td>
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<tr>
<td>$V_a$(MV)</td>
<td>5.12</td>
<td>8.17</td>
<td>13.46</td>
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<tr>
<td>$P_{\text{beam}}$(W)</td>
<td>1660</td>
<td>2640</td>
<td>2600*</td>
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<tr>
<td>$Q_{\text{beam}}$</td>
<td>$9.1\times10^7$</td>
<td>$9.1\times10^7$</td>
<td>$1.4\times10^8$</td>
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<tr>
<td>$P_g$(W)</td>
<td>3320</td>
<td>5280</td>
<td>5200</td>
</tr>
<tr>
<td>$Q_L$</td>
<td>$3.0\times10^7$</td>
<td>$3.0\times10^7$</td>
<td>$4.7\times10^7$</td>
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<tr>
<td>Control bandwidth</td>
<td>25</td>
<td>25</td>
<td>16</td>
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<tr>
<td>$\Delta_{\text{allowed}}$(Hz)</td>
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*Decreased from maximum value due to transit time factor
Prototype $\beta=0.47$ Cryomodule (THP70)

- Helium Dewar
- Helium Supply
- Support Link
- Outer Magnetic Shield
- Thermal Intercept Shield
- Inner Magnetic Shield
- AlignmentViewport
- Titanium Alignment Rails
- LN2 Supply/Return
- Sensor & Instrumentation Port

- Beta - 0.47
- Superconducting Cavity
- Cavity Tuner
  - Mechanical - Slow
  - Piezoelectric - Fast
- Fundamental Power Coupler & Moveable Transmission Line Transformer
$\beta = 0.47$ Tuner-Cavity-Power Coupler

Tuner

He Vessel

Power Coupler
$\beta=0.47$ Module Assembly
$\beta=0.47$ Module Assembly
$\beta = 0.47$ Module Assembly
$\beta=0.47$ Module Assembly (Feb 04)
805MHz 10kW Amplifier

- THALES TH382 air-cooled vacuum tetrode w/ a TH18482 cavity
Cavity and microphonics circuit

- $Q_{ext, fixed} \approx 1 \times 10^7$
- $Q_{ext, transformer} \approx 10^5$ to $4 \times 10^9$

Diagram:
- Network Analyzer/Signal Generator
- SRF Cavity
- Fixed input coupler
- Piezo fast tuner
- Transmission line transformer
- DSP
- Adaptive feedforward
- Real-time error signal
- Phase shifter
- Attenuator
- IF
- LO
- RF
External/room temperature tuner

Coarse Tuner Exercises on Cavity #2 at 4.22K

- $f_0 = 805.585$ MHz

Piezo Tuner Measurements on Cavity #2 at 4.20K

- $f_0 = 805.554$ MHz

- Fine tuner ~ 10 kHz
  - 90 μm piezoelectric (PI)

Coarse tuner ~ 1 MHz
Tuner Bode diagram

- **Magnitude**
  - Y-axis: 0 to 0.1
  - Grid: 0.02, 0.04, 0.06, 0.08

- **Phase (degrees)**
  - Y-axis: -180 to 180
  - Grid: 0, 45, 90, 135, 180

- **Frequency (Hz)**
  - X-axis: 0 to 100
  - Grid: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Active damping

- Adaptive feedforward cancellation of sinusoidal disturbances (TUP76)

6.5 Hz helium oscillation

57 Hz electric motor
Summary

• Protype elliptical cryomodule has demonstrated requirements for RIA
• Continue testing thru 2005
  – LLRF controls and high power testing
  – Improved passive & active microphonics control
• Invitation to colleagues interested in high $Q_L$ operation
  – Test LLRF & microphonic control techniques
$\beta = 0.47$ Module Clean Room Assembly (Nov ‘03)
$\beta=0.47$ 4-Cavity Module

- Shield Supply & Return
- He Supply
- He Return
- Alignment View Port
- External Tuner
- Top feed FPC
- Tri-Link
- He Return Line
$\beta = 0.47$ Module Cross-Section

- Support Link
- Top Plate
- He Supply
- Ti Rails
- He Return
- Tuner
- Power Coupler
\[ \beta = 0.47 \text{ Module End View} \]
Cold Mass Transport from JLAB to MSU (Nov ‘03)
β=0.47 Module Assembly at MSU
$\beta = 0.47$ Module Assembly at MSU
$\beta = 0.47$ Module Assembly at MSU
$\beta=0.47$ Module Assembly at MSU
\[ \beta = 0.47 \] Module Assembly at MSU
$\beta = 0.47$ Module Assembly at MSU
β=0.47 Module Test Results (March 04)

- Static load ~10 W at 2 K
- Power coupler operating at full power
- External frequency tuner
  - 1 MHz range with resonance near center
  - Piezoelectric operational
- High field tests
  - Approaching design gradients (32.5 MV/m and 64.2 mT peak)
  - Limited by X-rays (100 mRem/hr) since no shielding
  - Calorimetry for Q measurements underway
- Microphonics
  - Design $Q_L=2 \times 10^7$, bandwidth~40 Hz
  - Preliminary measurements show peak microphonic levels less than design bandwidth
$\beta = 0.47$ R&D Program

e-beam welding and first test performed at JLab
NSCL SRF R&D Facility
NSCL SRF Chemistry Facility

BCP Pumping System

- Temperature: <15 C
- Heat Exchanger: 5 kW
- Filtration: 4 microns
- Speed: 8 gpm