CEBAF Tuners: 1980 - 2018

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Introduction

• A number of different cryomodules are (have been) in operation at CEBAF
  – C20/C50
  – Renascence (C100 Prototype)
  – C100
• The CMs have unique tuner styles
• Microphonics issues found during testing and operation have been solved by both design and retroactive modification
CEBAF Cryomodules

C20/C50
- Original CEBAF cryomodules (C20)
- Reworked to create C50 cryomodules

Renascence
- CEBAF Upgrade prototype

C100
- Upgrade CEBAF cryomodules
## Overview

<table>
<thead>
<tr>
<th></th>
<th>CEBAF (C20/C50)</th>
<th>CEBAF Upgrade (Renascence)</th>
<th>CEBAF Upgrade (C100)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cavity</strong></td>
<td>5-Cell</td>
<td>7-Cell</td>
<td>7-Cell</td>
</tr>
<tr>
<td><strong>Frequency (MHz)</strong></td>
<td>1497</td>
<td>1497</td>
<td>1497</td>
</tr>
<tr>
<td><strong>Gradient per Cavity (MV/m)</strong></td>
<td>5</td>
<td>18</td>
<td>19.2</td>
</tr>
<tr>
<td><strong>Operating Mode</strong></td>
<td>CW</td>
<td>CW</td>
<td>CW</td>
</tr>
<tr>
<td><strong>Bandwidth (Hz)</strong></td>
<td>220</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>$Q_{\text{external}}$</td>
<td>$6.6 \times 10^6$</td>
<td>$2.0 \times 10^7$</td>
<td>$2.0 \times 10^7$</td>
</tr>
<tr>
<td><strong>Lorentz Detuning (Hz)</strong></td>
<td>75</td>
<td>324</td>
<td>312</td>
</tr>
<tr>
<td><strong>Microphonics (Hz, 6σ)</strong></td>
<td>-</td>
<td>±10</td>
<td>±10</td>
</tr>
<tr>
<td><strong>Stiffness (lb/in)</strong></td>
<td>26,000</td>
<td>20,000-40,000</td>
<td>37,000</td>
</tr>
<tr>
<td><strong>Sensitivity (Hz/µm)</strong></td>
<td>373 (calc)</td>
<td>~300 (calc)</td>
<td>267 (calc)</td>
</tr>
</tbody>
</table>

J. Delayen, *Tuning Systems, USPAS 2008*
## C20/C50 Tuner specs

<table>
<thead>
<tr>
<th></th>
<th>C20/C50 Tuner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Range (kHz)</td>
<td>+/- 200</td>
</tr>
<tr>
<td>Coarse Resolution (Hz)</td>
<td>NA</td>
</tr>
<tr>
<td>Backlash (Hz)</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Fine Range</td>
<td>None</td>
</tr>
<tr>
<td>Fine Resolution (Hz)</td>
<td>N/A</td>
</tr>
<tr>
<td>Tuning Method</td>
<td>Tension/Comp</td>
</tr>
<tr>
<td>Tuner Environment</td>
<td>Immersed (He)</td>
</tr>
<tr>
<td>Drive Environment</td>
<td>Vacuum/Warm</td>
</tr>
<tr>
<td>Motor Stoke (in)</td>
<td>0.25</td>
</tr>
</tbody>
</table>

P. Kneisel, J. Mamosser, *Mechanical Tuner for 5-Cell Cavity*, JLab Tech Note TN91-043
C20/C50 Tuner

• The tuner is attached to the first cell with a fixed cell holder, and to the fifth with a swivel cell holder.
• 4 cells are tuned, with the 5th being fixed
• A rigid titanium rod connects the two holders at one end and a drive shaft assembly connects the two at the other end.
• Tuning is accomplished by translating rotational motion of the worm/wheel gear assembly into axial movement of the swivel cell holder

J. Marshall, J. Preble, W. Schneider, Superconducting Cavity Tuner Performance at CEBAF, PAC 1993
C20/C50 Tuner Performance

- Feedback control system measures the phase difference between the forward and transmitted power, calculates the tuning angle, and drives the tuner stepper motor.
- 20 degrees of phase shift corresponds to 41 Hz of frequency shift.
- Changes in angle results from fluctuations in helium bath pressure, where +/- 1 torr results in shift of 100 Hz.
- At the design gradient of 5 MV/m, the frequency shifts ~75 Hz due to radiation pressure.

C20/C50 Tuner Issues

- Early production tuners had several functional issues (see below):
  a) Backlash caused by motor-to-tuner gear slop
  b) Cell/cell holder thermal mismatch
  c) Deadband due to lack of cavity/tuner pre-stress
- Hysteresis at resonance was +/- 10 kHz, mostly due to cell/holder gap
- Excessive motor operation could lead to repairs every 7 years against expected maintenance every 10 years

C20/C50 Tuner Remedies

• Difference in thermal coefficients between aluminum and Nb results in inherent hysteresis
• Holders were manufactured as half-cells matching contours of the cavities
• Final assembly included the addition of shims (~0.010 thick)
• Deadband was shifted to 30 KHz under resonance
• Plots show +/- 50kHz and +/- 5kHz hysteresis loops
• Cell holder shapes have been modified for use in new C75 cryomodules

Figure 3. ±50 kHz hysteresis loop of a cavity-tuner assembly tested in the fall of 1992.

## Renascence Tuner Specs

<table>
<thead>
<tr>
<th></th>
<th>Renascence Tuner</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coarse Range (kHz)</strong></td>
<td>&gt; 400</td>
</tr>
<tr>
<td><strong>Coarse Resolution (Hz)</strong></td>
<td>&lt; 100</td>
</tr>
<tr>
<td><strong>Backlash (Hz)</strong></td>
<td>&lt; 25</td>
</tr>
<tr>
<td><strong>Fine Range (kHz)</strong></td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Fine Resolution (Hz)</strong></td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Tuning Method</strong></td>
<td>Tension</td>
</tr>
<tr>
<td><strong>Tuner Environment</strong></td>
<td>Vacuum</td>
</tr>
<tr>
<td><strong>Drive Environment</strong></td>
<td>Vacuum/Cold</td>
</tr>
</tbody>
</table>
Renascence Tuner

- Phytron Stepper Motor
- Harmonic Drive
- Piezo Stacks
- Dicronite Coated BeCu M12x1.5 Spindle
- Axial Movement
- Primary Lever
- Secondary Lever
Renascence Tuner Features

• New HOM design for upgrade cavities left no beamline space for cavity tuner
• Renascence tuner is designed to apply a large force over a relatively short distance; it has a mechanical advantage of 30:1
• Coarse tuning is via a Phytron stepper motor (200 steps/rev) attached to a Harmonic Drive (Ratio 100:1)
• Fine tuning is via a 40mm Piezo stack
• Components are in insulating vacuum and operate cold
• Vacuum vessel included flange ports to allow for motor and piezo replacement

E. Daly, G.K. Davis, W.R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities*, PAC 2005
Renascence Tuner Operation

- Tuner is installed on individual cavity helium vessels
- Cavities tuned in tension by stepper motor and harmonic drive (ratio 100:1)
- Motor pushes one end of the primary lever downwards
- Primary lever motion causes secondary lever to rotate about pins and stretch cavity in tension
- Secondary lever ensures even load distribution on cavity
- Piezo actuator stacks are compressively loaded as motor is actuated
- Piezos can compress or expand to provide fine tuning

E.Daly, G.K. Davis, W.R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities*, PAC 2005
Renascence Tuner Performance

- Tuner was tested on Low Loss (LL004) and High Gradient (HGPT) cavities
- Tuner range:
  - 1000 kHz (spec 400kHz)
- Tuning sensitivity (top graph):
  - 0.73 Hz per step for HGPT
  - 0.57 Hz/step for LL004
- Decrease in frequency change is due to tuning mechanism following cosine function
- Piezo response:
  - 0.35 – 0.60 Hz/volt (bottom graph)
- Possible reliability issues with cold motor/piezos caused this tuner design to be scrapped for future C100 cryomodules

E. Daly, G. K. Davis, W. R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities*, PAC 2005
<table>
<thead>
<tr>
<th>Specification</th>
<th>C100 Tuner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Range (kHz)</td>
<td>+/- 200</td>
</tr>
<tr>
<td>Coarse Resolution (Hz)</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Backlash (Hz)</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Fine Range</td>
<td>550 Hz (150V)</td>
</tr>
<tr>
<td>Fine Resolution (Hz)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Tuning Method</td>
<td>Tension</td>
</tr>
<tr>
<td>Tuner Environment</td>
<td>Vacuum</td>
</tr>
<tr>
<td>Drive Environment</td>
<td>Vacuum/Warm</td>
</tr>
</tbody>
</table>
C100 Tuner

- Motor
- Pivot Plate
- Concentric Tubes
- Fulcrum Bar
- Flexure Joints
- Axial Movement
C100 Tuner

- Stepper Motor
  - 200 step/rev
- Harmonic Drive
  - Gear Reduction = 80:1
- Low voltage piezo
  - 50 µm stroke (150 V)
- Ball screw
  - Lead = 4 mm
  - Pitch = 25.75 mm
- Bellows/slides
  - axial thermal contraction

C100 Tuner Features

- Scissor jack mechanism
  - Ti-6Al-4V Cold flexures & fulcrum bars
  - Cavity tuned in tension only
- Warm transmission
  - Stepper motor, harmonic drive, piezo and ball screw mounted on top of CM
  - Openings required in shielding and vacuum tank
  - Originally due to a lack of confidence in the reliability of cold motor systems

E.F. Daly, *Overview of Existing Tuner Systems*, ERL Workshop 18-23
MAR 2005
C100 Tuner Operation

- Motion transferred through concentric tubes moving axially, relative to one another
- Tubes engage scissor-jack assembly
  - Attached to hubs on cavity
  - Pivots against fulcrum bars
  - Downward motion of ball-screw causes cavity stretch
- Piezo stacks originally installed as back-up for coarse tuner not being able to fine tune
- No bellows between cavities
  - Need to accommodate thermal contraction of cavity string
  - Pre-load and offset each tuner while warm

G. Davis, J. Delayen, M. Drury, E. Feldl, Development and Testing of a Prototype Tuner for the CEBAF Upgrade Cryomodule
C100 Tuner Performance

- **Coarse Tuner:**
  - Range: 343 kHz
  - Resolution: < 2 Hz
  - Hysteresis (at 700 Hz): 153 Hz
  - Repeatability (at 700 Hz): 37 Hz

- **Fine Tuner (Piezo):**
  - Range: 2.4 kHz
  - Resolution: 1 Hz
  - Hysteresis (at 2.5 kHz): 933 Hz
  - Repeatability (at 2.5 kHz): 329 Hz

- **Note:** Piezo stacks are currently only installed on one C100 in the CEBAF tunnel

G. Davis, J. Delayen, M. Drury, E. Feldl, *Development and Testing of a Prototype Tuner for the CEBAF Upgrade Cryomodule*
C100 Microphonics

• Operational microphonics were found to be higher than the 10 Hz spec
• The cause was determined to be cost-saving measures that reduced the stiffness of the tuner/cavity
• Thicker Pivot Plates were proposed as the simplest solution
• New setup tested warm on test bench, and on C100-5 in the tunnel
• New design (C100-4 onwards) showed marked improvement
• Retrofits applied to C100-1 to C100-3
  – Stiffen tuner stack
  – Bracing for waveguides
  – Bricks and bags (see T.Powers talk)

C100 Microphonics

Warm Transfer Function Measurements

- Improvements to the tuner stiffness did not significantly affect the axial vibrational response of the cavity.
- Improvements to the tuner stiffness did reduce the lateral, bending, modes of the cavity. It also reduced cavity response to the 10 Hz rigid-body mode of the entire 8-cavity string.

C100 Microphonics

Comparison of C100-1 (Original Tuner) and C100-5 (Stiffened Tuner)

Original Tuner (Top) and Stiffened Tuner (Bottom)

• The microphonics are substantially smaller in the cryomodule with stiffened tuners.
• The harmonics at 10 Hz and 45 Hz were substantially reduced in the cryomodule with the stiffened tuners.
• The 25 Hz component in C100-1 was not reduced substantially in C100-5. However, it was shifted up in frequency slightly as predicted by the modeling and warm tests.
• Operational testing in the CEBAF LINAC show an average of 47% improvement for ambient microphonic detuning for C100-5 (modified tuner) vs C100-1 (baseline tuner).
• Studies ongoing to use piezos to control microphonics

<table>
<thead>
<tr>
<th>Cryomodule</th>
<th>C100-1 (baseline)</th>
<th>C100-5 (modified)</th>
<th>% Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity 1</td>
<td>11.8 Hz</td>
<td>5.1 Hz</td>
<td>57%</td>
</tr>
<tr>
<td>Cavity 2</td>
<td>12.8 Hz</td>
<td>6.7 Hz</td>
<td>48%</td>
</tr>
<tr>
<td>Cavity 3</td>
<td>13.7 Hz</td>
<td>5.6 Hz</td>
<td>59%</td>
</tr>
<tr>
<td>Cavity 4</td>
<td>13.5 Hz</td>
<td>7.4 Hz</td>
<td>46%</td>
</tr>
<tr>
<td>Cavity 5</td>
<td>18.0 Hz</td>
<td>9.6 Hz</td>
<td>46%</td>
</tr>
<tr>
<td>Cavity 6</td>
<td>9.1 Hz</td>
<td>8.5 Hz</td>
<td>8%</td>
</tr>
<tr>
<td>Cavity 7</td>
<td>9.7 Hz</td>
<td>5.6 Hz</td>
<td>42%</td>
</tr>
<tr>
<td>Cavity 8</td>
<td>8.9 Hz</td>
<td>5.8 Hz</td>
<td>35%</td>
</tr>
</tbody>
</table>

Operational Microphonics in the CEBAF Tunnel, Baseline vs Modified Design (Peak Detuning)

Summary

• Unique tuners are in operation on several cryomodule/cavity types in the CEBAF tunnel
• C20/C50 tuners and C100 tuners are in current operation, and the Renascence-style tuner was also tested in the tunnel
• Lessons from testing and operations lead to improvements in design

Questions?