High Q Cavities for the Cornell ERL Main Linac

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5 GeV, 100 mA CW beam, 8 pm emittance, 2 ps bunches

~200 W HOM power/cavity
CW operation, $Q(1.8 \text{ K}) = 2 \times 10^{10} @ 16.2 \text{ MV/m}$
Science with an Energy Recovery Linac

Cornell Energy Recovery Linac:
Project Definition Design Report

June 2013

ERL documentation:
(1) Science, (2) Generic design

- Science case gathered in international workshops
- Design report
  - 530 pages between conceptual design and engineering design
  - Access at www.classe.cornell.edu/ERL/PDDR
• HTC-1: Follow vertical assembly procedure as closely as possible

• HTC-2: Include side mounted, **high power RF input coupler**

• HTC-3: Full cryo-module assembly: high power RF input coupler and **beam line HOM loads**
• Cavity exceeded Q specification at 1.8 K by 50%, reaching $3 \times 10^{10}$
• $Q(1.6 \text{ K, 5 MV/m}) = 6 \times 10^{10}$
• Exceeded gradient specifications
• RF-based and calorimetric-based Q measurements yielded consistent values
Most of the Parts:
316 Stainless Steel
with 5μ Copper Coating
Main Linac Input Coupler Testing

Power rating: 5 kW CW
Headroom for 10 kW

Designed by Cornell
Built by CPI
- Quality factor, gradient specifications achieved
- Administrative limits prevented higher field measurements (not limited by quench)
- Lower Q (than HTC-1) due to high radiation levels
Beamline HOM absorbers strongly damp dipole HOMs to under $Q \sim 10^4$
Initial Cooldown at 16.2 MV/m

Q(2.0 K) = 2.5 \times 10^{10}
Q(1.8 K) = 3.5 \times 10^{10}
Q(1.6 K) = 5.0 \times 10^{10}

10 K thermal cycle at 16.2 MV/m

Q(2.0 K) = 3.5 \times 10^{10}
Q(1.8 K) = 6.0 \times 10^{10}
Q(1.6 K) = 10.0 \times 10^{10}
Are we (just) lucky?
Total 64 cryomodules, each:
- six packages of 7-cell cavity/Coupler/tuner
- a SC magnets/BPMs package
- five regular HOMs/two taper HOMs
• Dec ‘12 – Design completed
• Jan ‘13 – Order 6 remaining input couplers (6 month fab)
• Feb ‘13 – 3 unstiffened cavity built, testing started
• Apr ‘13 – Award vacuum vessel PO (6 month fab) & HGRP (6 month)
• July ‘13 – Production of 3 stiffened cavities started
• Sept. ‘13 – In-house fabrication of string components complete (tuners, HOMs, tapers…)
• Nov. ‘13 – Begin string assembly in clean room
• March ‘14 – Begin cold mass assembly and instrumentation (outside clean room)
• End of ‘14 – MLC ready for testing
Un-stiffened cavities (#2, #3, #4)

ERL 7-cell surface preparations
1. Bulk BCP (140um)
2. Degassing in TM furnace (650C*4days)
3. Freq. and flatness Tuning
4. Final BCP (10um)
5. 120C bake in TM furnace (120C*48hrs)
6. HF rinse
7. VT w/ T-map
## Process summary ERL cavities

<table>
<thead>
<tr>
<th></th>
<th>ERL7-1 (HTC)</th>
<th>ERL7-2</th>
<th>ERL7-3</th>
<th>ERL7-4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk BCP</strong></td>
<td>140um (witness sample)</td>
<td>135 ± 10 um (cavity equator)</td>
<td>138 ± 5 um (cavity equator)</td>
<td>132 ± 7 um (cavity equator)</td>
</tr>
<tr>
<td><strong>Degassing</strong></td>
<td>Jlab, 650C*10hrs</td>
<td>TM-furnace 650C*4days</td>
<td>TM-furnace 650C*4days</td>
<td>TM-furnace 650C*4days</td>
</tr>
<tr>
<td><strong>tuning</strong></td>
<td>88%</td>
<td>94%</td>
<td>91%</td>
<td>92%</td>
</tr>
<tr>
<td><strong>Final BCP</strong></td>
<td>10 um</td>
<td>10 um</td>
<td>10 um</td>
<td>10 um</td>
</tr>
<tr>
<td><strong>120C bake</strong></td>
<td>On insert</td>
<td>TM-furnace</td>
<td>On insert</td>
<td>TM-furnace</td>
</tr>
<tr>
<td><strong>HF rinse</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>VT 1st (1.8K)</strong></td>
<td>17MV/m, 1.6e10 (No T-map, old insert)</td>
<td>17MV/m, 1.53e10 w/ T-map</td>
<td>Limited by FE w/ T-map</td>
<td>17.4MV/m, 2.4e10 w/ T-map</td>
</tr>
<tr>
<td><strong>Re-process</strong></td>
<td>-BCP(10um) -120C bake (in clean room, old set-up) -HF rinse</td>
<td>-Cavity length is too long, re-built &amp; re-test are planned</td>
<td>Re-process to cure FE -BCP(10um) -120C bake(TM-furnace) -HF rinse</td>
<td>HTC3, 16.2MV/m, 6.0e10 @1.8K</td>
</tr>
<tr>
<td></td>
<td>17MV/m, 2.8e10 No T-map (PC down)</td>
<td>17MV/m, 2.8e10 No T-map (PC down)</td>
<td>17MV/m, 2.8e10 No T-map (PC down)</td>
<td>17MV/m, 2.8e10 No T-map (PC down)</td>
</tr>
</tbody>
</table>
Vertical Test Cavity #4

1.00E+11

1.00E+10

1.00E+09

Eacc [MV/m]

Qo

2K meas.

1.8K meas.

1.6K meas.

ERL7-4 2K, 1st power rise (before quench)

ERL7-4 2K, 2nd power rise (after quench)

ERL7-4, 1.8K

ERL7-4, 1.6K
Are we (just) lucky?

Well, at least we are happy!
ERL Injector Prototype:
Achievements to date:

- 75 mA average current @ 4 MeV
- 0.3 μm emittance @ 77 pC, 8 MeV
Using a Na$_2$KSb photocathode, ran over 8 hours at 65 mA (2000 C) with a 2.6 day 1/e cathode lifetime. Reached as high as 75 mA for a short time.
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