Performance of the Cornell ERL Main Linac Prototype Cryomodule

Fumio FURUTA
Cornell University

On behalf of
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Outline

• Cornell ERL
• Module components
  – Cavities, VT and HTC results
  – Magnetic shielding
  – Couplers
  – HOM absorbers
• MLC cool down
• Summary
CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation.

5 GeV, 100 mA, 8 pm emittances, 2 ps bunch length, 16 MV/m cw, $Q > 2 \times 10^{10}$, 200 W HOM power per cavity,

PDDR: https://www.classe.cornell.edu/Research/ERL/PDDR.html

9/18/2015, SRF2015, Whistler  F. Furuta, Cornell University
ERL 7-cells VT at 1.8K

- Bulk BCP + high temp. bake + light BCP + 120degC*48hrs bake + HF rinse
- Average $Q_0 = (3.0 \pm 0.3) \times 10^{10}$ at 16.2MV/m, 1.8K (design $Q_0 = 2.0 \times 10^{10}$).
- FE free, no quench, admin. limit.
1) Better mag. Shielding in HTC

HTC has much better mag. shielding than VT dewar. $R_{\text{res}}$ was reduced from 11nOhm (VT) to 3.2nOhm (HTC-1)
2) Thermal cycle to above Tc is beneficial

Initial Cooldown at 16.2 MV/m

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Quality Factor Q₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 K</td>
<td>2.5 x 10¹⁰</td>
</tr>
<tr>
<td>1.8 K</td>
<td>3.5 x 10¹⁰</td>
</tr>
<tr>
<td>1.6 K</td>
<td>5.0 x 10¹⁰</td>
</tr>
</tbody>
</table>

R_{res} = 3.2 nΩ

10 K thermal cycle at 16.2 MV/m

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Quality Factor Q₀</th>
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<tbody>
<tr>
<td>2.0 K</td>
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</tr>
<tr>
<td>1.8 K</td>
<td>6.0 x 10¹⁰</td>
</tr>
<tr>
<td>1.6 K</td>
<td>10.0 x 10¹⁰</td>
</tr>
</tbody>
</table>

R_{res} = 1.3 nΩ

- Slow cool down rate through Tc; ~0.4 K/h
- Small cavity temp. gradient; ~0.2 K
Magnetic shielding

- Three layers of magnetic shielding:
  - Vacuum Vessel (carbon steel)
  - 80/40 K magnetic shield enclosing the cold mass
  - 2 K magnetic shield enclosing individual cavities
- Power rating: 5 kW CW
- $Q_{ext}: 6 \times 10^7$
- Designed by Cornell
- Built by CPI
Beamline HOM absorbers strongly damp dipole HOMs to under $Q \sim 10^4$
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**THBA05**

- No charge-up of the HOM ceramics observed
- HOM heating was less than expected
MLC assembly at Newman lab
MLC in Wilson LOE
Heat exchanger can
CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation.

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**Cryogenic sketch**

| 1 line for 2K supply | Subcooled liquid @1.2 bar | • 2K helium bath for cavities via 2K-2 phase line  
• Pre-cool gas for cool-down  
• 90% heat load from RF losses in the cavities |
| 2 lines for 4.5-6K | 3.0 bar He liquid  
Single phase flow | • Thermal intercept for HOM absorbers and couplers  
• 2/3 dynamic heat load |
| 3 lines for 40-80K | 20 bar He gas | • Thermal intercept for HOM absorbers and couplers  
• 40K thermal shield  
• 90% heat load from HOM |
Prototype MLC Cooling schematic
MLC and HXC Plumbing
MLC Cool down

Cool down target:
- 4k/h from room temp. to 80K
- dT<20K on 80K shield

Actual
- ~1.3k/h from room temp. to 80K
- dT~15K on 80K shield.

MLC 80K shield temperature

Reached 80K on Sept. 15th Wed.!

Keep going now

Cool down starts on Sept. 8th Tue.

9/18/2015, SRF2015, Whistler

F. Furuta, Cornell University
MLC shrinkage during cool down

$\Delta \sim 6\text{mm at } 80\text{K}$

T@80K shield

T@HGRP

Post position

CLASSE facilities are operated by the Cornell Laboratory for Elementary Particle Physics (LEPP) and the Cornell High Energy Synchrotron Source (CHESS) with major support from the National Science Foundation.
A new ELOG entry has been submitted:
Logbook: MLC  Message ID: 32
Entry time: Thu Sep 17 14:49:03 2015 (EDT)
Author: Peter Quigley
Type: Routine
Category: General
Subject: MLC Cooldown Status

MLC cooldown is complete!
Pump skid is running and operating for 1.8K.
Setup for RF is next.
Details later today.
Alarm Handler is running in CESR Control room.

Peter Quigley for The Team.
- ERL7-7 will be the 1st cavity to test in MLC.
- ERL7-7 VT results was 3e10 at 16MV/m, 1.8K.
## MLC Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
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<tbody>
<tr>
<td>Dec 2012</td>
<td>Design completed</td>
</tr>
<tr>
<td>Jan. 2013</td>
<td>Order 6 remaining input couplers (6 month fab)</td>
</tr>
<tr>
<td>Feb. 2013</td>
<td>3 unstiffened cavity built, testing started</td>
</tr>
<tr>
<td>Apr. 2013</td>
<td>Award vacuum vessel PO (6 month fab) &amp; HGRP (6 month)</td>
</tr>
<tr>
<td>July 2013</td>
<td>Production of 3 stiffened cavities started</td>
</tr>
<tr>
<td>Sept. 2013</td>
<td>In-house fabrication of string components complete (tuners, HOMs, tapers...)</td>
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<tr>
<td>Jan. 2014</td>
<td>Begin string assembly in clean room</td>
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<tr>
<td>May 2014</td>
<td>Begin cold mass assembly and instrumentation (outside clean room)</td>
</tr>
<tr>
<td>End of 2014</td>
<td>Cold mass assembly complete, MLC ready for moving</td>
</tr>
<tr>
<td>Mar 2015</td>
<td>Moving MLC from Newman to Wilson</td>
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<tr>
<td>July 2015</td>
<td>Begin MLC installation in Wilson L0E and cool down preparation</td>
</tr>
<tr>
<td>Sept. 2015</td>
<td>MLC cool down starts and completed. Cavity RF test will start (2weeks/cavity, Q(E), tuner, HOM, HPC, microphonic, etc..)</td>
</tr>
<tr>
<td>End of 2015</td>
<td>Will complete cavity RF test</td>
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The Cornell-BNL FFAG-ERL Test Accelerator

Future

1. Clear out the experimental hall (3 months, year 1)
2. Install the injector and linac cryomodule (3 months, year 1)
3. Install cryogenics and RF power (2 months, year 1)
4. Commission the injector and cryomodule (3-6 months, year 1)
5. Commission single-turn FFAG-ERL (6 months, year 2)
6. Install FFAG magnets and arcs (4 months, year 2)
7. Commission FFAG return loops (year 3)
8. FFAG experiments (year 3)

Summary

• All MLC components had been tested successfully and assembled into cold mass.
• World record high-Q had achieved during HTC 7-cell test, 3.5e10(2K), 6e10(1.8K), 1e11(1.6K)
• Essences of Cornell’s ERL high-Q cavities are 1) good mag. shielding, 2) Thermal cycle to above Tc is beneficial
• MLC cool down starts in Wilson lab on Sept. 8th, completed on Sept 17th, Pump skid is running and operating for 1.8K.
• From room temp. to 80K, Cool down rate is about 1.3K, dT over 80K shield is kept ~15K during cool down.
• RF test will start after conference, one cavity test at once, 2weeks/cavity.
• thermal cycle will be applied to improve Qo.
Acknowledgement

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Tobey Moore, Peter Quigley, Mike Ray, Dan Sabol,
James Sears, Colby Shore, Eric Smith
Vadim Veshcherevich, Dwight Widger

Shift table during room temp. to 80K cool