Superconducting RF: HWR Status

Zachary A. Conway, Argonne National Laboratory
Contributors: A. Barcikowski, B.M. Guilfoyle, C.S. Hopper, M.P. Kelly, M.J. Kedzie, S.h. Kim, P.N. Ostroumov and T.C. Reid

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Overview

• Work scope.
• Status reports:
  – Half-wave resonators.
    • Fabrication/Processing.
    • Cold testing.
  – Sub-systems.
    • RF couplers.
    • Solenoids.
    • Tuners.
    • BPMs.
  – Cryomodule.
    • Testing.
    • Assembly.
• Progress toward FY2016 deliverables.
• FY2017 plans.
• Summary.

162.5 MHz $\beta = 0.11$ Half-Wave Resonator (HWR)

48” (122cm)
Scope of Work

• Provide FNAL with a 2 K superconducting half-wave resonator cryomodule operating at 162.5 MHz for the acceleration of H⁻ beams from 2.1 to 10.3 MeV.
  - Delivered to PXIE for beam commissioning starting in 2018.

• HWR Cryomodule Major Tasks:
  - Develop the 2 K design, build the hardware (except the conduction cooled magnet leads), off-line pre-commission, deliver and install the cryomodule.
  - The cryomodule will have 8 162.5 MHz half-wave resonators, 8 6 T superconducting solenoids with integral return and steering coils and 8 beam position monitors (BPMs).
  - Satisfy all functional requirement specifications and Interface Document conditions.
Half-Wave Resonator Cryomodule

Conduction Cooled Leads (FNAL)
Helium Manifold
Helium Relief Port
Sub-Atmospheric HTXG Output
Cooldown Manifold
Ti Strong-Back
Slow Tuner Gas Heat Exchanger
Half-Wave Resonator
Vacuum Manifold
SC Solenoid

2.2 m X 2.2 m X 6.2 m
Technical Developments

• Novel design of half-wave resonators: double conical structure to reduce peak fields and cryogenic load while providing a high shunt impedance.

• Integrate into the superconducting solenoid a return coil and x-y steering coils without additional magnetic shielding.

• Cold, low-particulate clean, beam position monitors.

• Compact lattice suitable for the acceleration of several mAs of H⁻ or proton beams.

• When finished the half-wave cryomodule will be the first superfluid helium cooled TEM-class cryomodule.
What goes into a half-wave cavity?

- **Cavity Design Parameters:**
  - Beam physics design.
  - RF Performance.
  - Fabrication.
  - Polishing.
  - Cleaning.
  - Assembly.
  - Safety standards.

<table>
<thead>
<tr>
<th>Cavity Type</th>
<th>HWR</th>
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</thead>
<tbody>
<tr>
<td>Freq. (MHz)</td>
<td>162.5</td>
</tr>
<tr>
<td>( \beta )</td>
<td>0.112</td>
</tr>
<tr>
<td>( l_{\text{eff}} ) (cm, ( \beta \lambda ))</td>
<td>20.68</td>
</tr>
<tr>
<td>( \frac{E_{pk}}{E_{acc}} )</td>
<td>4.7</td>
</tr>
<tr>
<td>( \frac{B_{pk}}{E_{acc}} ) (mT/(MV/m))</td>
<td>5.0</td>
</tr>
<tr>
<td>( QR_s ) (( \Omega ))</td>
<td>48.1</td>
</tr>
<tr>
<td>( R_{sh}/Q ) (( \Omega ))</td>
<td>272</td>
</tr>
</tbody>
</table>
Half-Wave Resonator Fabrication Status

• We are building 9 total resonators.
  – The two prototypes are finished.
  – The remaining 7 production cavities are at various stages of finished:
    • All fabrication is finished. Only processing remains.
    • The first unit tested last month.
    • The second unit is ready for cold testing. Test will take place in the next several weeks.
    • Two units are ready for final light polishing (20 μm).
    • Three units are ready for hydrogen degassing at FNAL. After the hydrogen degassing they will be tuned and made ready for the final light polishing.

• Next:
  – Recent cavity test results.
  – Frequency tuning progress.
ANL-FNAL Collaboration on SRF Cavity Processing

Clean facilities for HPR & Assembly

1.3 GHz Cavity Electropolishing, 325 MHz BCP

72 MHz Cavity Electropolishing

650 MHz Cavity Electropolishing

3/15/2016

Conway | 2016 P2MAC
Half-Wave Resonator Q Curves

![Graph showing B_pk (mT) vs. F_pk (MV/m) for different prototypes.]

- **Prototypes**: HWR0 2K, HWR1 2K, HWR2 2K
- **Design Goal**: 1st Production HWR
- **2 W Cavity Power**

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**Accelerating Gradient (MV/m)**

0 5 10 15 20 25

**V_gain (MV)**

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

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RF Power Couplers

Left – Cold RF window and bellows assembly
- The ‘2 K’ flange is the upper CF flange in this view
- The ‘80 K’ flange is the lower CF flange

Right – Complete coupler assembly as viewed from below the half-wave cavity

- 1st Coupler assembly was thermally stable and tested at RF powers up to 5 kW. Currently testing the remaining coupler assemblies.
Half-Wave Resonators & Solenoids

- Solenoid package integrates x-y steering coils.

- Important design issue:
  - Minimize stray field @ the RF cavity to prevent performance degradation due to trapped magnetic flux.

- Measured RF surface resistance with a sensitivity of ±0.1 nOhm before and after each quench of the cavity.

- The cavity was quenched with the solenoid and the steering coils energized.

- No quantifiable change measured in the cavity RF surface resistance with the magnets energized.

Cavity quenched x10 at this field level.

Same result for steering coils.

Magnetic Field at the Solenoid Center (T)
Tuners and BPMs

• All of the tuners have been fabricated.
  – A tuner was tested on the cavity during the last test to finalize the cavity frequency tuning numbers.
  – The remainder of the off-line cavity tests will have the production tuners included too.

• The BPMs are fabricated but not welded into their bellows/flanges. To be finished by the end of FY2016.
Half-Wave Resonator Frequency Tuning

• Target frequency at 2.0 K = 162.500 MHz.
  – Includes ½ range of slow-tuner = 60 kHz.
  – Full slow tuner range = 120 kHz.

• During the last 2.0 K test the frequency = 162.461 MHz.
  – Need to tune frequency higher by 40 kHz.
  – This is due to a 40 kHz pre-load being applied to the slow-tuner during installation.

• The second production cavity test will confirm the above number. Then we will fine-tune all of the cavities and confirm the correct $f_0$ during subsequent tests.
Cryomodule Assembly Status

• We have aligned and installed the Ti strong-back in the cryomodule.

• We are preparing to cool this assembly down to:
  – Measure alignment changes.
  – Quantify the 70 K heat leak.
  – Initial cold leak checking.

• After this we will perform a “mock” assembly to verify our procedures.
<table>
<thead>
<tr>
<th>Deliverables</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Complete fabrication of magnet assemblies.</td>
<td>Finished</td>
</tr>
<tr>
<td>2  Complete fabrication of sub-systems (RF couplers, slow tuners and BPMs)</td>
<td>In progress.</td>
</tr>
<tr>
<td>3  Engineering cool down of the cryomodule to 80 K.</td>
<td>Going on right now.</td>
</tr>
<tr>
<td>4  Complete RF surface processing of 7 production cavities.</td>
<td>In progress ~75% finished.</td>
</tr>
<tr>
<td>5  Testing of 7 production cavities individually in the test cryostat.</td>
<td>In progress.</td>
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</table>
## Fiscal Year 2017 Deliverables

<table>
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</thead>
<tbody>
<tr>
<td>1  Assembly of the cryomodule.</td>
<td>Not started.</td>
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<tr>
<td>2  Vacuum and cryogenic testing of the cryomodule at LN2 temperature, 77 K.</td>
<td>Not started.</td>
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<tr>
<td>3  Delivery and installation at FNAL</td>
<td>Not started.</td>
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We are currently on target to meet our FY17 delivery goal.
Summary

• Progress is being made on all aspects of the cryomodule fabrication.

• We are in the early stages of the cryomodule assembly while we finish the cavities, couplers and sub systems.

• We are on track to deliver the cryomodule in FY17 in preparation for FY18 beam commissioning.