Achieving High Peak Fields and Low Residual Resistance in Half-Wave Cavities

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Acknowlegements

- Argonne National Laboratory Personnel:

- Many Vendors:
  - Advanced Energy Systems, NY.
  - Adron EDM, WI.
  - Numerical Precision, IL.
  - Meyer Tool and Manufacturing, IL.

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

48” (122cm)
A new half-wave resonator (HWR) cryomodule for FNAL’s PIP-II project.

<table>
<thead>
<tr>
<th>Half-Wave Resonator</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Operating Voltage</td>
<td>2 MV/cavity</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>2.0 K</td>
</tr>
<tr>
<td>Maximum Dynamic Load</td>
<td>2 W/cavity</td>
</tr>
</tbody>
</table>

HWR Cryomodule for PIP-II

2.2 m X 2.2 m X 6.2 m

V. Yakovlev, TUAA05
What goes into a half-wave cavity?

- The complex cavity system:
  - Beam physics design.
  - RF Performance.
  - Fabrication.
  - Polishing.
  - Cleaning.
  - Assembly.
  - Safety standards.

- RF Performance:
  - Maximize voltage gain.
  - Low cryogenic load.
  - Low peak surface fields.
  - Design supports fabrication, processing and cleaning.

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

- Cavities are built largely in house with critical vendors.
- ANL does intermediate QA.
- EDM.
- Keyhole EB welding in all high-field regions.
- Significant hand polishing.

Electrostatic Discharge Machining

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Cavity Polishing and Processing

- All polishing is done after fabrication is finished.
- Cooling water flow through space between helium jacket and Nb cavity.
- Unique Argonne Low-Beta Cavity EP Tool.
  - S.M. Gerbick et al, SRF’11.
  - M.P. Kelly et al, SRF’11.
- Successful many times with QWRs:
Clean facilities for HPR & Assembly

72 MHz Cavity Electropolishing

1.3 GHz Cavity Electropolishing, 325 MHz BCP

650 MHz Cavity Electropolishing
Hydrogen Degassing @ FNAL

625°C High-Vacuum Bake thanks to M. Merio and A. Rowe (FNAL).
Cold Test & Cooldown

- Cavity hung beneath a large helium reservoir.
- Silicon diodes are used for temperature measurement.
- Cavity cooled to 4 K with dewars.
  - Rapid cooling 165 – 50 K.
- Entire bath pumped to 2.0 K.

![Graph showing temperature vs. time with labeled SC Transition and 1-5 K Offset in Measurements.](image-url)
162.5 MHz HWR Q Curves

![Graph showing Q curves for different temperatures and accelerating gradients.]

- Bpk (mT) vs. Epk (MV/m)
- Accelerating Gradient (MV/m) vs. Vgain (MV)
- 2K Design Goal
- 2.0 K
- 4.2 K
- 2 W
Based on weakly coupled energy decay time.

Ambient magnetic field 0-40 mG mostly aligned with the axis of the cavity. Fluxgate magnetometers used for this measurement.
Concluding Remarks

- Highly optimized cavities.
  - RF Performance improved by increase volume over which the magnetic energy is distributed.
  - Including fabrication and processing.

- Constantly working to improve cavity fabrication and processing.

- High peak fields achieved.
  - Peak Electric > 70 MV/m.
  - Peak Magnetic Field no fundamental limit observed.

- Low residual resistance:
  - Low field 1.7 - 2.3 nΩ.
  - Full range 1.7 – 8 nΩ.
  - @ operating voltage of 2 MV/cavity 2.3 – 2.7 nΩ.
    - < 1 W into helium bath for $E_{pk} = 45$ MV/m and $B_{pk} = 48$ mT.