Cornell ERL’s Main Linac Cavities

N. Valles for Cornell ERL Team
• RF Design Work
  – Cavity Design Considerations
  – Optimization Methods
  – Results
• Other Design Considerations
  – Coupler Kicks
  – Stiffening Rings, Mechanical Resonances
• Prototype Cavity Results
• Conclusions
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Cavity Design Goals

• Maximize Threshold Current through linac
  – Require > 100 mA at 77 pC bunch charge
• Minimize cryogenic losses due to fundamental
• Maintain low peak fields (Epk/Eacc < 2.1)
• Obtain robust design w.r.t. machining variation
Naïve Method

• Very computationally expensive!

Better Method

• Determine analytical goal function from scaling laws and optimize it
• Single cavity result
• Optimization then only requires a field solver, saving particle tracking as a verification of design
• Use parallel computing to speed optimization

\[ I_{th} \propto \left( \frac{R}{Q} \right) \frac{1}{(Q_L)_\lambda} \frac{1}{\omega_\lambda} \cdot \frac{1}{T_{12}^* \sin(\omega_\lambda t_r)} \]
Goal Function from Scaling Laws

\[ \zeta_\lambda = \left( \frac{R}{Q} \right)_\lambda \frac{\sqrt{Q_\lambda}}{f_\lambda} \]
Baseline Design

Center cells with increased cell-to-cell coupling

Increasing cell-to-cell coupling results in less variation of HOM properties for a given dimensional error, leading to increased threshold current through the linac.
Beam-Break Up Simulations

- Optimize Cavity W.R.T. BBU parameter
- Introduce realistic shape variations (x400/error)
- Compute dipole HOMs to 10 GHz (1692 modes /cavity)
- Generate realistic ERL (x100)
- Compute BBU current

± 0.125 mm error

± 0.250 mm error

± 0.500 mm error

± 1.000 mm error

Variation in ellipse parameters

Loosened machining tolerances increase relative cavity-to-cavity frequency spread.
Specific Manufacturing Defects

Cell Length Error

Cell Radius Error

Deformed Cell Surface

Elliptically Deformed Cell

Cell with Bump

Liling Xiao, Kwok Ko, Ki Hwan Lee, Cho-Kuen Ng, SLAC, Menlo Park, U.S.A
Matthias Liepe, Nicholas Valles, Cornell University, Ithaca, NY, U.S.A

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Threshold Current Results

Design Well Exceeds Cornell ERL Threshold Current Specification!
Overview

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Goal to minimize the effect of the coupler on the beam. Necessary for low emittance operation.

S3P calculations performed on NERSC cluster
• Small bandwidth cavity vulnerable to detuning caused by microphonics, especially helium pressure fluctuations

• Diameter of cavity stiffening rings used as free parameter to reduce $df/dp$

• ANSYS simulations show that large diameter, small diameter, or no rings at all have smallest $df/dp$

• Tuner requirements rule out largest diameter stiffening rings

• Manufacturing easier with no rings

• Small/no rings make cavity fragile and lower mechanical resonant frequencies

Sam Posen
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Prototype Cavity Fabrication

Quality control: CMM and frequency check

Finished main linac cavity with very tight ($\pm 0.250$ mm) shape precision $\Rightarrow$ important for supporting high currents (avoid risk of trapped HOMs!)
Prototype Cavity Pre-Test Treatment

- Fabricated with 85% field flatness
- Heavy BCP
- Outgassing (>600 C)
- Tuned to 95% field flatness
- Light BCP
- Ultrasonic cleaning
- HPR 16 hr
- 120° bake 48 hr
First CERL 7-Cell RF Test Results

Quality Factor vs. \( E_{\text{acc}} \) [MV/m]

- Admin. Limited
- No Radiation
- No Quench

F. Furuta, A. Ganshyn, M. Ge, N. Valles
Cornell University 2011-Oct
BCS Resistance [$\Omega$]

- $T_c = 9.15$ K
- $\Delta/KT_c = 1.94$
- $\lambda_L = 36.0$ nm
- $\xi_0 = 64.0$ nm
- $\text{RRR} = 11.8$
- $R_0 = 11.4$ n$\Omega$

Data
Srimp Fit
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• Conclusions
• The cavity design for the CERL main linac has been completed
  – Cavity design optimized with respect to beam-break up current
  – Simulations show linac supports > 400 mA current
  – Coupler kick and mechanical simulations are consistent with high quality beam requirements

• Prototype Cavity Fabricated and Tested
  – Fabrication: Cavity meets tight shape tolerances
  – RF Test: Cavity met specifications on first test
  – Next steps: maintaining performance with HOM absorbers and when in horizontal test cryostat
• Test of prototype cavity without and with beam (up to 100 mA)

• Build and test full main linac SRF cryomodule
Special Thanks to:

- ERL 2011 Committee
- Cornell SRF Group
- Cornell ERL Team
- SLAC Advanced Comp Group: L. Xiao, K. Ko, K. Lee, C. Ng
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For more information see:

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