Commissioning of the High Current ERL Injector at Cornell

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for the Cornell ERL team
Design parameter:
- Nominal bunch charge: 77 pC
- Bunch repetition rate: 1.3 GHz
- Beam power: up to 550 kW
- Nominal gun voltage: 500 kV
- SC linac beam energy gain: 5 to 15 MeV
- Beam current: 100 mA at 5 MeV, 33 mA at 15 MeV
- Bunch length: 0.6 mm (rms)
- Transverse emittance: < 1 mm-mrad
Measured normalized beam emittance at ~fC bunch charge (5 MeV):

0.2 to 0.4 mm mrad
(in both planes)

Good agreement with predictions from thermal limit at cathode and utilized laser spot size.

→ Next step: optimizing injector for 77 pC operation

• Implemented fast (~5 s), “single button” measurement
• Will be used for parametric optimization of the injector
Comparison of beam measurements with simulations

**Beam properties at the cathode**

- Fixed slits phase space measurements
  - Corrector coils for beam scanning
  - 10 to 20 micron precision slits
  - 1 kW beam power handling

Good agreement with theory gives confidence that the very small simulated emittances can be achieved.

Phase space measured after the beam was transported through the accelerator.

Implemented global beam position feedback which uses all BPMs, corrector, and dipole magnets.
Beam Orbit Control

Implemented global beam position feedback which uses all BPMs, corrector, and dipole magnets.
**Transverse Deflecting Cavity**

- Number of cavities: 1
- Max transverse kick voltage: 200 kV
- Max RF power: 3.8 kW
- Average power: 200 W
- Pulse duration: 60 µs
- Max rep. rate: 1 kHz

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**Images:**
- Unstreaked beam
- Streaked beam

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**Diagram:**
- Tuner and tuner mechanism
- Input coupler
- Water cooling channel
- Protrusion
- Beam pipe
- Field probe
- Pumping port
• Achieved maximum current is about 9 mA
• Main limitations:  - Gun high voltage instabilities
                 - Laser amplitude / position instabilities

→ Work on solving the stability issues is in progress
Strange beam response of 250 kV beam

Steering the beam differently through the cryomodules changed the beam shape (no RF field in cavities)
Strange beam response

corrector pair

cryomodule

beam position measurement

vertical corrector (A)

horizontal corrector (A)

vertical beam position (mm)

horizontal beam position (mm)
Localizing stray fields in the cryomodule with DC coupler-kicks

Generation of electrical DC fields in the coupler regions of the SRF cavities

**dipole-like field**

**quadrupole-like field**

Electrical field vectors

horizontal position (mm)

vertical position (mm)
Localizing stray fields in the cryomodule with DC coupler-kicks

dipole-like coupler kick

corrector pair

cryomodule

beam position measurement

coupler 1

coupler 2

coupler 3

coupler 4

coupler 5

vert. corr. strength

deflection of the beam after the cryomodule due to the coupler field

hor. corrector strength
Localizing stray fields in the cryomodule with DC coupler-kicks

quadrupole-like coupler kick

corrector pair

cryomodule

beam position measurement

coupler 1

coupler 2

coupler 3

coupler 4

coupler 5

vert. corr. strength

hor. corrector strength

hor. corrector strength

hor. corrector strength

hor. corrector strength

hor. corrector strength

deflection of the beam after the cryomodule due to the coupler field
Localizing stray fields in the cryomodule with DC coupler-kicks

Determined the origin of the stray fields:

- Coupler 2
- Center of 3\(^{rd}\) HOM absorber
- Coupler 3
- Coupler 4
In-situ demagnetization

Warm up and in-situ demagnetization removed stray fields
Stray fields

- Stray fields reappeared after a beam loss in the cryomodule
- Coupler conditioning changed the stray fields
  \( \rightarrow \) Charging up of HOM absorbers!
<table>
<thead>
<tr>
<th><strong>Total # loads</strong></th>
<th>3 @ 78mm + 3 @ 106mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power per load</strong></td>
<td>26 W (200 W max)</td>
</tr>
<tr>
<td><strong>HOM frequency range</strong></td>
<td>1.4 – 100 GHz</td>
</tr>
<tr>
<td><strong>Operating temperature</strong></td>
<td>80 K</td>
</tr>
<tr>
<td><strong>Coolant</strong></td>
<td>He Gas</td>
</tr>
<tr>
<td><strong>RF absorbing tiles</strong></td>
<td>TT2, Co2Z, Ceralloy</td>
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Low conductivity of HOM absorber tiles: Can hold charge for many days / weeks!

Worst offender: **Ceramic 137Zr10**, followed by ferrite Co2Z and TT2

Small beam loss charged up absorber tiles -> kV **electric** fields at beam position!
Removing inner tiles

Consequence of low resistivities of absorber materials:
• Completely removed ceramic 137Zr10
• Tried gold coating of TTE absorbers but coating may fall off

→ Removed all tiles from the inside of the HOM absorber

Found one loose tile during cryomodule disassembly
• Thermal stress tests confirmed this problem
→ Solved by cutting stress relief slots in the tiles
Power limitations with modified HOM absorbers

Blue: inside and outside ferrites
Red: outside ferrites only

![Graph showing power limitations with modified HOM absorbers](image)
Power limitations with modified HOM absorbers

Power loss in the metal walls

Blue: inside and outside ferrites
Red: outside ferrites only

$P_{\text{wall}} / P_{\text{total}}$

$f [\text{MHz}]$

$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^0$

$2000$ $2500$ $3000$ $3500$ $4000$ $4500$ $5000$
Cavity Quality Factors

Averaged quality factor $Q_0$ vs. $E_{acc}$ for all cavities together

Had difficulties with low cavity quality factors

- $Q$ factors degraded over time
  $\Rightarrow$ Q disease?

During the rebuild, all cavities were high pressure rinsed
  $\Rightarrow$ $Q$ restored to $1.6 \times 10^{10}$ at 1.8 K
  $\Rightarrow$ no Q disease
  $\Rightarrow$ cavities were possibly contaminated with particles?
Current status of the injector cryomodule

• Cryomodule is rebuilt and back in the injector
• Cooled down to 4 K
• 2 K cool-down planned for next Monday

→ Ready to see beam in the next weeks!
Conclusion and Outlook

Charging up of the HOM absorbers caused difficulties during the first commissioning

→ Rebuild cryomodule during the last 6 months and removed problematic absorbers

Still, many critical systems could be successfully commissioned and prepared.

• Measured thermal beam emittance as expected
• Could increase beam current to 9 mA for short times (limitations understood and being worked on)

First beam operation after cryomodule rebuilt expected end of March

• Emittance optimization at 77 pC
• Work on high current beam operation