Cavity design for KEK-ERL main linac

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TTC topical meeting on CW SRF

KEK ERL main linac group

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Contents

• Requirement for ERL main linac cavity
• HOM damping
• Surface electric field
  – Cavity performance and Field emission
Requirement for ERL main linac cavity

• Maximum $E_{acc} = 15 \sim 20$ MV/m
  ➢ Operation: $12 \sim 15$ MV/m

• $Q_0 > 1 \times 10^{10}$ at 15 MV/m
  ➢ Lower cryogenic loss is desirable

• **CW operation**
  ➢ HOM damping $\rightarrow$ high current operation
  ➢ Suppression of field emission

Cavity design is focused on HOM suppression (designed at 2006)

> 200 main linac SRF cavities on straight section

From 「Energy Recovery Linac Preliminary Design Report」
HOM Strategy and cavity design

- **Dipole mode**: Lower impedance of \((R/Q)Q_{ext}/f\)
- **Monopole mode**: Avoid frequency around 2.6GHz, 5.2GHz ...
- **Quadrupole mode**: Eccentric fluted beampipe
- **Packing factor**: Select 9cell structure

1) Iris diameter 80mm, elliptical shape at equator
2) Large beampipes(\(\phi 100/123\text{mm}\)) mounted with RF absorber

Main parameters for the acceleration mode

<table>
<thead>
<tr>
<th>Frequency</th>
<th>1300 MHz</th>
<th>Coupling</th>
<th>3.8 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rsh/Q</td>
<td>897 Ω</td>
<td>Qo x Rs</td>
<td>289 Ω</td>
</tr>
<tr>
<td>Ep/Eacc</td>
<td>3.0</td>
<td>Hp/Eacc</td>
<td>42.5 Oe/(MV/m)</td>
</tr>
</tbody>
</table>
BBU threshold are significantly improved
More than 600mA is possible for KEK-ERL model-2 cavity
Monopole mode

KEK-ERL model-2 cavity

Around 2.6 GHz

\[ R_{sh}/Q \] vs. Frequency [GHz]

No monopole modes around 2.6GHz and 5.2GHz, within +/- 40MHz

Around 5.2 GHz

\[ R_{sh}/Q \] vs. Frequency [GHz]

Need to avoid resonant excitation for the case of lower frequency ERL operations.
Cavity performance and Field emission
Surface electric field of cavity

Effect of large iris diameter
HOM suppression ⇔ Large $E_{peak}$

• Field emission becomes the cryogenic losses and radiation, which could be problem under CW operation.
• So, it is important to suppress field emission for ERL operation.
X-ray mapping was observed by using rotating type mapping system.
High power cryomodule test

Q values are dropped due to field emission.

Radiation monitor (Both sides of module)
During conditioning X-ray burst happened.

Before burst at 14MV

After burst at 11.9MV

Si PIN diode around beam axis
Summary and future

• KEK-ERL main linac cavity was designed mainly focused on HOM damping

• At present, field emission is problem
  – Cavity design?
  – Module assembly technique?

• Future direction
  – Improvement of module assembly technique is essential.
  – New cavity design with lower surface E field, but still keeping HOM damping as strong as possible, is desirable.
**Discussion**

- **HOM**
  - How high frequencies should we calculate/measure HOMs, in order to confirm BBU threshold and HOM heating?
    - \( \sim \text{ps beam} \rightarrow \text{beam spectrum } \sim 1\text{THz} \)
    - Before construct hundreds of cavities (multi GeV ERL), we want to confirm cavity performance.

- **Field emission**
  - How field emission is severe/ or not severe for ERL operation?
    - Radiation safety
    - Cryogenic loss
    - Really run inside cavities up to \( \sim \text{GeV} \)?
  - How is the situation of field emissions for running CW SRF facilities?
  - During operation, what’s happen?
    - Gradually degraded?
    - Processed?
Backup slide
Dependence of number of cells

- Study for TESLA + large beampipe
  – Impedance becomes half for 7-cell cavity

<table>
<thead>
<tr>
<th></th>
<th>9 cell</th>
<th>7 cell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R_{sh}/Q$</td>
<td>$Q$</td>
</tr>
<tr>
<td>TM011</td>
<td>$\pi/9$</td>
<td>159</td>
</tr>
<tr>
<td>TM012</td>
<td>$8\pi/9$</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>$R_{t}/Q$</td>
<td>$Q$</td>
</tr>
<tr>
<td>TM110</td>
<td>$5\pi/9$</td>
<td>9</td>
</tr>
<tr>
<td>TE-iris</td>
<td>23</td>
<td>4256</td>
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</table>
**Study on iris diameter**

<table>
<thead>
<tr>
<th></th>
<th>TM010</th>
<th>TE-iris</th>
<th></th>
<th></th>
<th></th>
<th>TM110</th>
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</thead>
<tbody>
<tr>
<td>Rsh/Q</td>
<td>Rt/Q</td>
<td>Qext</td>
<td>Rt/Q</td>
<td>Qext</td>
<td>Rt/Q</td>
<td>Qext</td>
<td>Rt/Q</td>
<td>Qext</td>
</tr>
<tr>
<td>70phi</td>
<td>1010</td>
<td>22</td>
<td>9500</td>
<td>80000</td>
<td>9</td>
<td>10000</td>
<td>49000</td>
<td></td>
</tr>
<tr>
<td>80phi</td>
<td>890</td>
<td>11</td>
<td>4000</td>
<td>18000</td>
<td>6</td>
<td>7600</td>
<td>24000</td>
<td></td>
</tr>
<tr>
<td>90phi</td>
<td>780</td>
<td>5</td>
<td>4600</td>
<td>13000</td>
<td>4</td>
<td>7000</td>
<td>13000</td>
<td></td>
</tr>
<tr>
<td>100phi</td>
<td>690</td>
<td>3</td>
<td>1000</td>
<td>1000</td>
<td>4</td>
<td>9700</td>
<td>24000</td>
<td></td>
</tr>
</tbody>
</table>

- **Condition of study**
  - Equator shape is same with TESLA cavity
  - Large beampipe of φ118 is used.
  - Both end cells are symmetric.

- **Generally, dipole modes are efficiently damped.**
Compact ERL(cERL) project

Demonstrate the technologies needed for future multi-GeV class ERL, and show its beam performances

**Parameters of the Compact ERL**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>35 - 200 MeV</td>
</tr>
<tr>
<td>Injection energy</td>
<td>5 MeV</td>
</tr>
<tr>
<td>Average current</td>
<td>10 - 100 mA</td>
</tr>
<tr>
<td>Acc. gradient (main linac)</td>
<td>15 MV/m</td>
</tr>
<tr>
<td>Normalized emittance</td>
<td>0.1 - 1 mm·mrad</td>
</tr>
<tr>
<td>Bunch length (rms)</td>
<td>1 - 3 ps (usual)</td>
</tr>
<tr>
<td></td>
<td>~ 100 fs (with B.C.)</td>
</tr>
<tr>
<td>RF frequency</td>
<td>1.3 GHz</td>
</tr>
</tbody>
</table>

※ red numbers are parameters for initial stage
**cERL main linac cryomodule**

- **9-cell SRF cavity**
  - HOM damped cavity
  - $E_{acc} = 15-20 \text{ MV/m}$
  - $Q_0 > 1 \times 10^{10}$ @15MV/m

- **HOM damper**
  - HIP ferrite on Cu beampipe
  - Operation at 80K
  - 150W HOM power handling

**Requirement**
- **Frequency:** 1.3 GHz
- **Input power:** 20kW CW (SW)
- **Gradient:** 15-20MV/m
- **$Q_0$:** $>1 \times 10^{10}$
- **Beam current:** max 100mA (HOM-BBU対策を施した空洞設計)

- **2-cavity cryomodule** had been developed for cERL main linac

**Input coupler**
- 20kW CW (total reflection)
- Cold and warm window
- HA997 ceramic is used
- $QL=(1-4)\times10^7$(variable)

**Frequency Tuner**
- Slide jack tuner
- Piezo tuner

**ERL model-2 9cell Nb空洞**
Module assembly

He jackets were welded on cavities

Cavities, HOM dampers and input couplers were assembled.

Installed into cryomodule. Gate valves were mounted on both sides.

Assemble He line, magnetic shield, sensors and so on
Field emission calculation

Trying to understand field emission by using simulation code, Fishpact etc.
High power test of cERL main linac cryomodule

#3 (Lower)  #4 (Upper)

Concrete shield

0.5m  0.92m  0.91m

1.0m  6m

30kWIOT

Radiation monitors
Dynamic loss measurement

**#4**
(Upper cavity)

- **Vc vs Q₀ (#4 cavity)**
- **Heat loss from He gas flow (#4 cavity)**

Q values are dropped due to field emission. Cryogenic loss also increase.

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**#3**
(Lower cavity)

- **Vc vs Q₀ (#3 cavity)**
- **Heat loss from He gas flow (#3 cavity)**

- y = 9.7263 + 0.11863x  \( R = 0.99893 \)