Characterization of microphonics in the compact ERL main linac cavities

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ERL2019, Berlin (HZB) . Sep. 15 ~ Sep. 20, 2019
Main Content

- Introduction
- LLRF and Tuner control system
- RF stabilities of the ML cavities
- Microphonomics measurement
- System identification of piezo tuner
- Summary
The Compact ERL (cERL) is a test facility to demonstrate ERL technology. It is a 1.3-GHz superconducting system and is operated in CW mode [1].

**Layout of cERL**

Injector consists of four cavities: Buncher (NC), Injector 1 (SC), Injector 2 (SC), Injector 3 (SC).

Main linac (ML) includes two nine-cell cavities (SC).

- April, 2013, injector commissioning.
- Oct. 2013, main linac commissioning.
Cavity and RF system

At present, total four kinds of power sources are applied in cERL: 8 kW SSA, 16 kW SSA, 25-kW klystron and 300 kW klystron.

RF requirement (need LLRF feedback)

- 0.1 % rms, 0.1 deg. rms for cERL
- 0.01% rms, 0.01deg.rms for 3GeV-ERL

~8.5 MV/m for main linac Cavities

~3 MV/m for Injector Cavities

<table>
<thead>
<tr>
<th>Cavity</th>
<th>QL</th>
<th>RF power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bun.</td>
<td>1.1e5</td>
<td>3 kW</td>
</tr>
<tr>
<td>Inj. 1</td>
<td>1.2e6</td>
<td>0.53 kW</td>
</tr>
<tr>
<td>Inj. 2</td>
<td>5.8e5</td>
<td>2.4 kW</td>
</tr>
<tr>
<td>Inj. 3</td>
<td>4.8e5</td>
<td></td>
</tr>
<tr>
<td>ML1</td>
<td>1.3e7</td>
<td>1.6 kW</td>
</tr>
<tr>
<td>ML2</td>
<td>1.0e7</td>
<td>2 kW</td>
</tr>
</tbody>
</table>

~20 MeV

0.4 MeV

1.3 GHz RF
MicroTCA-based digital low level radio frequency (LLRF) system and tuner resonance control system are applied in cERL.

- **Piezo Driver**: -250V~+250V
- **SSA Cavity**
- **Motor Driver**: (CW/CCW pulse)
- **I/Q Mod.**
- **EPICS**
- **ADC & DAC Interface**
- **Digital I/O**
- **Micro TCA.0 board**
  - FPGA vertix5-FX
  - 16-bit DAC × 4 ch
  - 16-bit ADC × 4 ch
  - Dig. I/O × 12 ch
  - Epics in Power PC

**Piezo Tuner**
- 0 V~500 V
- Stroke = 4 μm @ 2 K
- 1 μm→300 Hz
- Cavity BW: 130 Hz (QL~1e7)

** Shaft of tuner**
**Flange**
**Slide-jack Tuner**

**PC**

**Ethernet**
LLRF & Tuner (Algorithm)

- Piezo Tuner: Integral (I) control.
- LLRF system: PI control.

Evaluate LLRF performance

\[
\begin{align*}
A &= \sqrt{I^2 + Q^2} \\
\theta &= \tan^{-1}\left(\frac{Q}{I}\right)
\end{align*}
\]

Motor Driver (CW/CCW pulse)

Piezo Driver -250V~+250V

Calibrate the detuning

\[
\Delta \omega = \omega_{0.5} \cdot \tan(\Delta \varphi)
\]

\[
\omega_{0.5} = \frac{f_{RF}}{2Q_L}
\]

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Performance of ML1 becomes worse in the past 5 years, ML2 performs well.
Some components (> 500 Hz) were excited in the cavity phase of ML1 in 2019.

FFT analysis
RF stabilities of ML1

Add rubber sheet under the scroll pump to remove the 50 Hz.

Cavity degrade due to field emission and thermal breakdown [2]

RF stabilities becomes worse due to the deteriorated microphonics conditions [3].
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In 2019, accidentally, we found that the back-ground microphones in ML1 depends on its cavity field.

Field-scanning (under feedback operation).

Field Scanning (cont’d)
Field Scanning

➢ Perform the FFT analysis of the detuning under different field, then plot the Map.

![FFT of \(\Delta \omega\)]

![Large \(\Delta \omega\)]

![Inc. Vc]

![Field & Detuning Maps]

![Small \(\Delta \omega\)]

![RMS \(\Delta \omega\)]

![RMS Vc phase stability]

![Cavity Phase]

![Detuning [Hz rms] or 40*Vc phase [deg rms]]

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ML1 Field Scanning (result)

- High frequency component's suddenly appears @ ~3.1 MV (Threshold $V_c$).
- Detuning and RF phase stabilities becomes worse under higher $V_c$.

$V_c = 5.9\text{MV}$

Threshold $V_c \approx 3.1\text{ MV}$

$V_c [\text{MV}] = 1.038 [\text{m}] \times E_{\text{acc}} [\text{MV/m}]$
The boundary appeared only in the ML1.

Why “field dependency microphonics”? The mechanism remains unclear.
Hysteresis Phenomena

Inc. Field: 3.18 MV
Dec. Field: 2.80 MV

Hysteresis phenomena?
The value of threshold $V_c$ is probably related with quench limits (remains unclear)?

### Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Threshold $V_c$ [MV]</th>
<th>Quench Limits [MV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3.07</td>
<td>6.16</td>
</tr>
<tr>
<td>II</td>
<td>3.34</td>
<td>6.51</td>
</tr>
<tr>
<td>III</td>
<td>3.18</td>
<td>6.30</td>
</tr>
<tr>
<td>IV</td>
<td>3.17</td>
<td>6.30</td>
</tr>
</tbody>
</table>
Simply increasing the FB gain is **NOT** a good method, some mechanical modes would be excited and the system therefore oscillated [4].

![340 Hz oscillation](image)

Advanced control methods (e.g. active compensation method [5], or active noise control [6]) are better choice, for these cases, a system model is usually necessary (or helpful). We have to know the system better.
Identification of the TF Model

- Transfer function (TF): Piezo to RF.
- Excite piezo with sinusoidal signal and sweep the frequency.
- FFT analysis → TF model.

Frequency Range: 5 Hz to 350 Hz
Frequency Step: 1 Hz
For each frequency point: 5 sec.

Obtain the frequency response with FFT analysis

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Obtain the frequency response with FFT analysis

<table>
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<tr>
<th>Frequency [Hz]</th>
<th>Mag. [dB]</th>
<th>Pha. [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>350 Hz</td>
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<td></td>
</tr>
</tbody>
</table>

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Piezo Transfer function is probably related with $\Delta \omega$.

$$H(s) = \left( \frac{M_0}{\tau s + 1} + \sum_{k=1}^{N} \frac{\omega_k^2 M_k}{s^2 + 2\xi_k\omega_k s + \omega_k^2} \right) e^{-T_d s}.$$
Validation of the TF Model

- Excite the system (and model) with square wave.
- TF Model vs. Actual System.
- We will optimize tuner control with TF model.

Input:

Type A
50 Hz

Type B
4a
20 Hz

Actual System

Response

Blue: Meas.
Red: model

Type A
Type B

Validation of the TF Model

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RF stabilities of ML1 cavity were getting worse due to the deteriorated microphonics in the past 5 years.

A “field level dependency microphonics” phenomenon was observed in ML1.

The threshold $V_c$ for the deteriorated microphonics is about 3.1 MV, and it is probably related with quench limits level.

We have identified and validate the TF model of the piezo tuner system and we plan to optimize the tuner control with this TF model.
Thank you for your attention


