Current Status of Microphonics and LLRF at cERL

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Introduction of cERL

Compact Energy Recovery Linac (cERL) : Test facility of 3-GeV ERL Project

Beam commissioning was started from Dec. 2013

RF = 1.3 GHz CW

Circumference ~ 90m

**Main linac module**

9-cell cavity × 2

\[ Q_L = 1 \times 10^7 \]

**Injector module**

2-cell cavity × 3

Double coupler

\[ Q_L = 4.8 \times 10^5 \]

\[ \sim 1.2 \times 10^6 \]
<table>
<thead>
<tr>
<th></th>
<th>Buncher</th>
<th>Inj-1</th>
<th>Inj-2</th>
<th>Inj-3</th>
<th>ML-1</th>
<th>ML-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>NC</td>
<td>2cell-SC</td>
<td>2cell-SC</td>
<td>2cell-SC</td>
<td>9cell-SC</td>
<td>9cell-SC</td>
</tr>
<tr>
<td>Cavity Voltage</td>
<td>114 kV</td>
<td>0.7 MV</td>
<td>0.7 MV</td>
<td>0.7 MV</td>
<td>8.6 MV</td>
<td>8.6 MV</td>
</tr>
<tr>
<td>Field Gradient (Design)</td>
<td>3 MV/m (7.5 MV/m)</td>
<td>3 MV/m (7.5 MV/m)</td>
<td>3 MV/m (7.5 MV/m)</td>
<td>8.3 MV/m (15 MV/m)</td>
<td>8.3 MV/m (15 MV/m)</td>
<td></td>
</tr>
<tr>
<td>Q_L</td>
<td>$1.1 \times 10^5$</td>
<td>$1.2 \times 10^6$</td>
<td>$5.8 \times 10^5$</td>
<td>$4.8 \times 10^5$</td>
<td>$1.3 \times 10^7$</td>
<td>$1.0 \times 10^7$</td>
</tr>
<tr>
<td>Cavity Length</td>
<td>0.068 m</td>
<td>0.23 m</td>
<td>0.23 m</td>
<td>0.23 m</td>
<td>1.036 m</td>
<td>1.036 m</td>
</tr>
<tr>
<td>RF Power @Low beam current</td>
<td>3 kW</td>
<td>0.53 kW</td>
<td>2.6 kW</td>
<td>1.6 kW</td>
<td>2 kW</td>
<td></td>
</tr>
</tbody>
</table>

Current status of high power RF sources

8 kW SSA

25kW Klystron

300kW Klystron

16 kW SSA

8 kW SSA

MRCW18, T.Miura (KEK)
Mechanical Resonance measurement of Inj. Cavities

Eacc: 1MV/m

Vibration was excited by using the piezo tuner to longitudinal direction.

Sinusoidal wave \((40V_{pp})\) was fed to piezo tuner.

Large mechanical resonance exists around 400 Hz.
Mechanical Resonance Measurement of ML Cavity

Large mechanical resonance exists near 50 Hz

Impulse hammer response with piezo

M. Satoh, IPAC2014
PASJ2013
Digital LLRF System at cERL

Mechanical tuner: coarse tuning

Piezo Tuner: fine tuning

Cavity pick-up signal

Resonance Tuning

KLY/SSA

Interlock

RF Switch

1310 MHz LO

Down converter

1300 MHz

10 MHz

Field FB board

MicroTCA

16-bit ADC (LTC2208) x 4ch
16-bit DAC (AD9783) x 4ch
Digital I/O x 12 ch
FPGA Virtex5-FX

DAC

-250V~250V

Piezo driver

Motor driver

CW/CCW pulse output

Offset +250V

Vc

Vf

Vf

Vr

Vref

CLK 80MHz

MRCW18, T.Miura (KEK)
Feedback Control: \( \Delta \theta = \theta_f \text{(input RF)} - \theta_c \text{(cav)} - \theta_{\text{offset}} \Rightarrow 0 \)

Block diagram of Tuner Control Board

Phase is calibrated by resonance scan

Current Settings:
- \( f_c = 100 \text{ Hz for INJ Cav} \)
- \( f_c = 20 \text{ Hz for ML Cav} \)

*100Hz analog LPF is equipped in ML Piezo driver.*
Waveforms of ML Cavities

ML1

\[ \Delta A = 0.012\% \text{ rms} \]
\[ \Delta \theta = 0.014^\circ \text{ rms} \]

\[ \Delta A = 0.035\% \text{ rms} \]
\[ \Delta \theta = 0.3^\circ \text{ rms} \]

Vc: w field Feedback

Vc: w/o field Feedback

ML2

\[ \Delta A = 0.013\% \text{ rms} \]
\[ \Delta \theta = 0.015^\circ \text{ rms} \]

\[ \Delta A = 0.15\% \text{ rms} \]
\[ \Delta \theta = 0.6^\circ \text{ rms} \]

Field fluctuation by Microphonics is stabilized by RF Feedback

T. Miura, IPAC2014 @Dresden

Microphonics
Phase noise measurement using Signal Source Analyzer

Microphonics is observed at 10 Hz - 400Hz.

Vc Phase Noise w/o RF FB (10Hz-1MHz) = 0.73 deg
Vc Phase Noise with RF FB (10Hz-1MHz) = 0.017 deg

Phase noise by Microphonics was suppressed well by RF FB.
Phase noise of Vc with FB was almost the same as that of Master Oscillator.
**Countermeasure against Scroll Pump Vibration**

9-cell SC cavity: \( Q_L = 10^7 \)

Field gradient
8.3 MV/m : Operation point
(15 MV/m : Design)

For constant input RF power

![Diagram](image)

The rubber sheet was inserted under the scroll pump. The 50 Hz vibration is suppressed.

MRCW18, T. Miura (KEK)
RF Performance

RF Stabilities for Short Time

<table>
<thead>
<tr>
<th></th>
<th>Inj1</th>
<th>Inj2 &amp; Inj3</th>
<th>ML1</th>
<th>ML2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>0.010% rms</td>
<td>0.012% rms</td>
<td>0.004% rms</td>
<td>0.004% rms</td>
</tr>
<tr>
<td>Phase</td>
<td>0.018° rms</td>
<td>0.022° rms</td>
<td>0.010° rms</td>
<td>0.009° rms</td>
</tr>
</tbody>
</table>

Almost satisfied the requirement of 3-GeV ERL

Measurement of Beam Momentum Stability
for confirmation of RF stability

Momentum drift of ~15 minutes period was observed.
What causes Energy Drift?

Time interval of detuning is similar to the interval of energy drift.

Large detuning was caused by valve control for liquid N₂.

Inj1  Inj2  Inj3  ~15 min.

<RF source: cavity =1:1>
Cavity phase is stabilized by RF FB.

<Vector-sum operation>
Vector-sum is constant.
But each cavity phase fluctuates.

Vector-sum error may cause energy drift.
β<1 @ Injector
By adopting high gain, the detuning due to liquid N₂ was improved.

Detuning phase

Cavity phase

By adopting high gain, the detuning due to liquid N₂ was improved.

<table>
<thead>
<tr>
<th>Cav</th>
<th>$\Delta \theta$ deg (rms)</th>
<th>$\Delta f$ Hz (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INJ1</td>
<td>0.23</td>
<td>2.2</td>
</tr>
<tr>
<td>INJ2</td>
<td>0.10</td>
<td>2.0</td>
</tr>
<tr>
<td>INJ3</td>
<td>0.09</td>
<td>2.1</td>
</tr>
<tr>
<td>ML1</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>ML2</td>
<td>0.16</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Inj2&Inj3 cavity phases became stable.
Stability of Beam Momentum (2)

Measurement after modification of tuner feedback gain

Large momentum drift disappeared.

=> Beam momentum jitter \( \Delta P/P = 0.003\% \) was achieved.

beam condition: 5 Hz, 300uA peak, 0.23pC/bunch, 1usec pulse width, Cam15: 62.6um/pixel, Dispersion: -2.387422 m@cam15
ERL Operation for 0.9 mA (1mA) Beam

ΔP_{total} = Δ(P_{in1} + P_{in2} - P_{ref1} - P_{ref2})

Power differences caused by beam loading was not observed. For 0.9 mA beam operation, 100±0.03 % energy was recovered.
For ML cavities, large Microphonics of 50 Hz was excited by the scroll pump. By using rubber sheet, the vibration was significantly decreased.

Detuning caused by valve control of liquid Nitrogen was observed. By improving resonance control gain, the detuning was suppressed. As a result, beam energy drift caused by the vector-sum error was also improved.

Beam momentum jitter $\Delta P/P = 0.003\%$ was achieved.

ERL operation for 0.9 mA beam was performed successfully.