Superconducting Cavity in SuperKEKB

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Abstract

The eight superconducting cavities (SCC) were operated in the electron ring of KEKB for more than ten years and are still operating in SuperKEKB. SCC is essential to provide high accelerating voltage and large beam power in SuperKEKB. One of main issues for SCC is the large HOM power due to high beam current. To cope with the large HOM power, additional SiC dampers have been installed to reduce the load of present ferrite dampers. Another issue is the degradation of Q-factors with field emission in several cavities due to long-term operation. We developed a horizontal high pressure rinsing method (HHPR) to remove field emitters. The Q-factors of cavities were successfully recovered to 1e9 at 2 MV by HHPR. We will report the measures against the large HOM power and the degraded performance recovery.

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Overview of SuperKEKB

• Searching for “new physics” beyond the Standard Model
• e-/e+ asymmetric energy ring collider for B-meson physics
• Target Peak Luminosity
  $8 \times 10^{35} \text{ /cm}^2\text{/s} = 800 \text{ /nb/s}$
  40 times of KEKB achieved
  ➢ **Nano-beam scheme** with colliding beams of 10µm x 40nm
  ➢ **Increase of Beam Intensity**
• Physics Run since 2019

Peak luminosity of $3.12 \times 10^{34} \text{ /cm}^2\text{/s}$
was recorded in June 2021.
Superconductive Cavity (SCC) in SuperKEKB

- SCC is essential to provide both the high accelerating voltage and the large beam power required by SuperKEKB.
- Main Issues for SCC in SuperKEKB
  - **Large HOM power** is expected due to twice high beam current. Measures against HOM power are necessary.
  - **Degradation of cavity performance of Qo** due to the long-term operation. For stable operation, performance must be recovered.

<table>
<thead>
<tr>
<th>SuperKEKB-SCC Design Parameters</th>
<th>KEKB-SCC Achieved Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Beam Current [A]</td>
<td>2.6</td>
</tr>
<tr>
<td>RF Voltage [MV/cav.]</td>
<td>1.5</td>
</tr>
<tr>
<td>External Q</td>
<td>5E+4</td>
</tr>
<tr>
<td>Unloaded Q (Q₀) at 2MV</td>
<td>1E+9</td>
</tr>
<tr>
<td>Beam Power [kW/cav.]</td>
<td>400</td>
</tr>
<tr>
<td>HOM Power [kW/cav.]</td>
<td>37</td>
</tr>
</tbody>
</table>

KEKB-SCC Achieved Parameters

- Beam Current [A]: 1.4
- Beam Power [kW/cav.]: 400
- HOM Power [kW/cav.]: 16

**Largest class in the world**

509 MHz

- Nb single-cell
- 4.4 K operation
- 8 SCCs in electron ring
- Re-use of SRF system of KEKB

SCC Modules in SuperKEKB Tunnel
SCC Module in SuperKEKB

- **Input Coupler**
- **Liquid He Port**
- **Ferrite HOM Damper**
- **Frequency Tuner**

509 MHz Nb Single-cell Cavity
4.4 K Operation
Issue 1: Measures against Large HOM Power

• A Pair of Ferrite HOM Dampers for each SCC
• Since 1998 (Start of KEKB)
• HOM power in KEKB: 16 kW/cavity (1.4A, \( \sigma = 6\text{mm} \), 10nC/bunch)
Study of HOM Power Flow in SuperKEKB

Wake field simulation using CST Particle Studio

<table>
<thead>
<tr>
<th></th>
<th>Eq.LF [V/pC]</th>
<th>HOM Load @2.6A[kW]</th>
<th>Eq.LF [V/pC]</th>
<th>HOM Load @2.6A[kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) to upstream</td>
<td>0.05</td>
<td>1.3</td>
<td>0.05</td>
<td>1.4</td>
</tr>
<tr>
<td>(2) to downstream</td>
<td>0.58</td>
<td>15.7</td>
<td>0.15</td>
<td>4.0</td>
</tr>
<tr>
<td>(3) SBP Ferrite</td>
<td>0.32</td>
<td>8.6</td>
<td>0.35</td>
<td>9.5</td>
</tr>
<tr>
<td>(4) LBP Ferrite</td>
<td>0.43</td>
<td>11.7</td>
<td>0.47</td>
<td>12.8</td>
</tr>
<tr>
<td>Total</td>
<td>1.38</td>
<td>37.4</td>
<td>1.02</td>
<td>27.7</td>
</tr>
<tr>
<td>(5) SiC</td>
<td>--</td>
<td>--</td>
<td>0.97</td>
<td>26.1</td>
</tr>
</tbody>
</table>

- Loads of SBP(3) and LBP(4) ferrite dampers are not large.
- Large HOM power is emitted through the downstream beam pipe(2).
- **The emitted power becomes the load of the downstream cavity.**
- **Additional SiC damper** (5) can absorb enough emission power.
- SiC damper can be installed without vacuum breaking of the cavity.
Results of Beam Study with SiC Damper

A set of SiC dampers has been installed to SCC section for beam test. The HOM power absorbed by the ferrite dampers of downstream cavity (D10B) was reduced >15% after SiC damper installation. It was confirmed that the expected large HOM power can be dealt with by the SiC damper. In order to achieve the design beam current, additional SiC dampers should be installed every downstream of the cavities.
Issue 2: Recovery of Degraded Cavity Performance

RF performance of SCC are degraded in the long-term operation.

• $Q_0$ of several cavities were significantly degraded at $\sim$2MV with Field Emission.
• Low $Q_0$ causes a high load on the cryogenic system.
• Degradation might be due to particle contamination during
  * repair of vacuum leak.
  * replacement of coupler gaskets to change $Q_{ext}$.

Performance recovery is desirable for stable long-term operation of SuperKEKB.
Horizontal High-Pressure Rinse (HHPR) system

- **New Horizontal High-Pressure Rinse (HHPR)** with ultrapure water system was developed.
- HHPR can be applied to the cavity without taking out from the cryomodule.
- The system is equipped with automatic nozzle driving system in horizontal and rotational.
- Input coupler, ferrite HOM dampers, bellows chambers and vacuum system are removed before HHPR in a clean booth.
- Water in the cell is pumped up by aspiration system during rinsing.
- Only cell and iris area are rinsed.
- We applied HHPR to degraded cavities.

### HHPR Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Pressure</td>
<td>7 MPa</td>
</tr>
<tr>
<td>Nozzle</td>
<td>φ0.54mm x 6</td>
</tr>
<tr>
<td>Driving speed</td>
<td>1 mm/sec.</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>6 deg./sec.</td>
</tr>
<tr>
<td>Rinsing time</td>
<td>15 min.</td>
</tr>
</tbody>
</table>
Results of HHPR

- We have already applied HHPR to three cryomodules degraded by strong Field Emission.
- HHPRed cavities were tested with high power at 4 K.
- Before cooling, baking were not performed.
- Cavity performances were successfully recovered.
- All three cavities have been installed and operated stably in SuperKEKB.
Summary

• SCC system has been operating stably with the high accelerating voltage in SuperKEKB.

• Measures against Large HOM Power
  • Additional SiC damper is effective to reduce emission power to the downstream, as expected in simulation.
  • To increase the beam current up to design, SiC damper should be installed to every downstream of the cavities.

• Performance Recover of Degraded Cavities
  • We developed HHPR method to remove contaminants on cavity surface.
  • Cavity performances were successfully recovered by HHPR.
  • The HHPRed cavities are operating in SuperKEKB stable.