### Calibration of SRF Cavity Voltage by Measurement of Synchrotron Frequency in SuperKEKB

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#### New Vc Calibration Method by fₛ Measurement

1. 4 base cavities: BaseVc = fₛ_base
2. Add a target cavity: BaseVc + TrgVc = Vc,tot
3. BaseVc = 6MV; TrgVc = 1.8MV
4. fₛ_max and fₛ_min are measured by searching RF phase scan of TrgVc > 180 deg.
5. Vc,tot measurement studies were carried out twice.
6. 8 SCCs were divided to Group A and B.
7. 1st study
   - Group A: target cavities
   - Group B: the base cavities
8. 2nd study (2 weeks after of 1st study)
   - Group A: the base cavities
   - Group B: target cavities
   - Single Bunch Beam (0.5mA)
   - Relative phase of cavities is adjusted in-phase in advance.

#### Evaluation of α

The α may be deviated from the design value by a few percent. To estimate the deviation of α, we focus on the calibration factors for Group A and B, named K_A and K_B. For the group of base cavities, the calibration factors for the base cavities are used for K_i (i=A, B). For the group of target cavities, an average of the calibration factors is used. The ratio K_A/K_B must be the same values in the 1st and 2nd studies, since no big change of cavity performance is expected during the two weeks between the 1st and 2nd studies.

α can be different between these studies since beam optics correction was performed between the 1st and 2nd studies. The deviation of α is defined as correction factors k_A and k_B for the two studies.

To further determine k_A and k_B, fₛ measurements with various combinations of cavities were carried out in 2021. The (fₛ_measured - fₛ_target)² value means the product of the correction of α and the correction of Vc,tot sin φ

By comparing #1 and the others, there is no considerable difference in the values of (fₛ_measured / fₛ_target)².

The values of k_A and k_B are almost the same.

#### Summary

- In order to solve the non-negligible discrepancy in the Vc calibration between the two methods using Qo or Qc, a new calibration method based on fₛ measurement is investigated. Studies on this calibration were performed in 2019 and 2021. From these studies, the Vc calibration factors were obtained with an accuracy of about 1%, independent of Qo or Qc.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>KEKB operation</th>
<th>SuperKEKB design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Current [A]</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Number of Bunches</td>
<td>1585</td>
<td>2500</td>
</tr>
<tr>
<td>Number of SRF Cavities</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Beam Power [kW/cav]</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Cavity Voltage [MV/cav]</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>HOM Power [kW/cav]</td>
<td>16</td>
<td>37</td>
</tr>
</tbody>
</table>

Main Issues:
- Large HOM Power: Additional SIC damper is installed as the countermeasure. The effect has been confirmed in the beam operation.
- Degradation of Q0: Horizontal High-Pressure Rinse of cavity has been established. Q0 were recovered to 1x10⁸ at 2MV/cavity in three cavities.
- For Stable Operation:
  - RF aging in every regular maintenance day (every 2 weeks)
  - Warm-up twice a year

The actual Vc for SCCs have been observed since 1998.

#### Summary of Calibration Factors Obtained from the fₛ Measurement Studies

<table>
<thead>
<tr>
<th>Cavity ID</th>
<th>D10A</th>
<th>D10B</th>
<th>D10C</th>
<th>D10D</th>
<th>D11A</th>
<th>D11B</th>
<th>D11C</th>
<th>D11D</th>
<th>D11D*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration Factor in 2019**</td>
<td>0.995</td>
<td>0.889</td>
<td>0.974</td>
<td>0.923</td>
<td>0.873</td>
<td>1.067</td>
<td>0.857</td>
<td>0.911</td>
<td>0.920</td>
</tr>
<tr>
<td>Factors in 2019 Study</td>
<td>0.977</td>
<td>0.910</td>
<td>0.998</td>
<td>0.946</td>
<td>0.894</td>
<td>1.094</td>
<td>0.878</td>
<td>0.934</td>
<td>-</td>
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**Correction of α by 2% is applied to the factors obtained 2019.

These new individual Vc calibration factors will be applied from the fall 2021 operation.

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### References

[1] SRF Cavity in SuperKEKB


[4] Number of SRF Cavities = 8 | 8


[6] Number of Bunches = 1585 | 2500


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**Vc Calibration by fₛ Measurement**

To solve the discrepancy of Vc, a new calibration method based on fₛ measurement is investigated.

- Using Beam
- Independent of Qo or Qc
- No High-Power RF measurement

**More Accurate Vc Calibration**

Error to Vc,tot
- parasitic energy loss
- Deviation of α from design

**Evaluation**

E_k: checked by an energy scan, which confirmed CM energy of beam is on the Y(4s) resonance as designed.

**Synchrotron Frequency fₛ**

\[ 2π fₛ = \sqrt{\frac{2π f_{Vc,tot}}{2π f_{Vc,tot}/π \sin \phi_i}} \]

\[ \phi_i = \arccos \left( \frac{U_D}{U_{Vc,tot}} \right) \]

**SuperKEKB HER Parameters**

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**Individual Vc calibration factors were obtained and applied to operation in 2019.**