Estimation of Impedances & Loss factors of SuperKEKB LER

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Introduction

- Beam duct of SKEKB is quite different from that of KEKB.
  - Cross-section: Circular duct → beam duct with antechambers
  - Diameter of beam channel (LER): 94 mm → 90 mm
  - Material: Cu → Al or Cu
- Designs of many components were changed and the loss factors and impedances of them have been estimated by using GdfidL. (LER only. HER is not yet.)
  - Bellows chamber
  - SR mask
  - Flange connection
  - Movable mask (Collimator)
  - Pumping port
  - BPM, BxB FB BPM
  - IP chamber
- Bunch \( q=1 \) C went through the center of the beam channel, and the wake potentials were monitored.
- Loss factor and impedance (longitudinal) were estimated from the wake potential.
  - Bunch length: 3 ~ 10 mm
  - Length of wake potential: 0.1 m (for loss factor calculation) 5.0 m (for impedance calculation)
  - Mesh size: \(~0.2\) mm
Bellows

- Bellows chamber with comb-type RF shield will be used in SKEKB.
  - There is no radial step on the inner surface.
    (There is a small step (~1 mm) in a conventional bellows chamber.)
  - RF is shielded by nested comb teeth.
    length : 10 mm
    radial thickness : 10 mm

SKEKB

KEKB
• Loss factor ($\sigma_z = 6$ mm)
  
  \[ k = 2.2 \times 10^{-3} \text{ V/pC} \]
  
  1000 pieces in one ring
  
  \[ k_{\text{total}} = 2.2 \text{ V/pC} \]

• Impedance

  It was found that there are trapped modes at 7.5 GHz and 25 GHz (over cut-off frequency (2.5GHz)). Effects of these trapped modes on the beams will be investigated.
**SR mask**

- SR mask is located at the side wall of the SR channel (antechamber).
  - The height of the SR mask is ~8 mm
  - Compared to KEKB, the effect of the SR mask on the beam will be very small.
**SR mask**

- **Loss factor ($\sigma_z = 6$ mm)**
  
  \[ k = 1.8 \times 10^{-15} \text{ V/pC} \]  
  (much smaller than KEKB)

  1000 pieces in one ring

  \[ k_{\text{total}} = 1.8 \times 10^{-12} \text{ V/pC} \]  
  (much smaller than other components)

- **Impedance**
  
  Negligible small.
**Pumping port**

- NEG strips are installed into the antechamber.
  - The antechamber for pump is isolated by using a screen with small holes (φ4mm).
  - GdfidL model with a length of 0.247 m was made for calculation.
Pumping port

• Loss factor ($\sigma_z = 6$ mm)
  
  $k_{0.247} \text{ m} = 90.2 \text{ V/C}$
  
  2200 m for 1 ring
  
  $k_{\text{total}} = 4.5 \times 10^{-7} \text{ V/pC}$  (much smaller than the conventional pumping port)

• Impedance
  
  – No trapped mode is found.
Flange connection

- MO-type flange will be used instead of the conventional one (Helicoflex gasket).
  - Inner surface is much smoother than the conventional one.
- Loss factor ($\sigma_z = 6 \text{ mm, type1}$)
  - $k = 1.28 \times 10^{-5} \text{ V/pC}$ \quad $k_{\text{total}} = 0.03 \text{ V/pC}$
  - Calculations for other bunch length are now in progress.
- Impedance
  - Calculations are now in progress.
**Movable mask & Taper**

- Basic design of the movable mask will be as same as the conventional one in the commissioning stage.
  - Cross-section of the mask chamber is circular with a diameter of 90 mm. (no antechambers)
  - The lengths of a ramp and a mask head are 200 mm and 20 mm, respectively.
  - The distance between a beam and the mask head is 10 mm.
  - The transition ducts (taper ducts) between the movable mask and the duct with antechambers are necessary at both sides of the movable mask.
Movable mask & Taper

- Loss factor ($\sigma_z = 6$ mm)
  \[ k = 2.31 \times 10^{-1} \text{ V/pC} \quad \text{(movable mask : } 2.31 \times 10^{-1}, \text{ taper duct : } 3.83 \times 10^{-4}) \]
  \[ k_{\text{total}} = 3.7 \text{ V/pC} \quad \text{(larger than other vacuum components)} \]

- Impedance
  Effect on the beam will be studied.
Resistive wall

- Wake fields were calculated from the following formulas.

\[
\frac{Z_m''}{L} = \frac{\omega Z_m'}{c} L = \left(1 + \frac{\delta_m}{\omega_0}\right) \frac{4}{bc} \left[\frac{2\pi \sigma}{\omega} \left[1 + \text{sgn}(\omega)\right]\right] \left[\frac{ib^2}{m+1} + \frac{\omega}{\omega} \right]
\]

Wake function : \( W_m'(z < 0) = \frac{2}{\pi} \int_0^\infty d\omega \text{Re} Z_m''(\omega) \cos \frac{\omega z}{c} \)

(A. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators")

- The beam duct does not have antechambers.
- (circular duct)
- The diameter of the duct is 90 mm.
  \((b = 4.5 \text{ cm})\)
- The beam duct is made of Cu or Al.
  \((\text{Conductivity } [\text{s}^{-1}] : \text{Cu}=5.4 \times 10^{17}, \text{Al}=3.2 \times 10^{17})\)
- The total duct length is 2200 m.

- Loss factor \((\sigma_z = 6 \text{ mm})\)

\[ k_{2200m} = 1.7 \text{ V/pC (Cu)} \]
\[ 2.3 \text{ V/pC (Al)} \]
BPM & BxB FB BPM
(M. Tobiyama)

- BPMs for high beam current were developed for SKEKB.
  - Reduction of the button electrode size (BPM), duct radius (BxB FB BPM), etc.
- Loss factor ($\sigma_z = 6 \text{ mm}$)
  - BMP : $k = 1.6 \times 10^{-4} \text{ V/pC}$
  - FB BMP : $k = 5.9 \times 10^{-4} \text{ V/pC}$
- Impedance
  - Growth rate of coupled bunch instability was estimated from this result, and it was confirmed that it is negligible small.
**IP chamber**

- Two types of IP chambers were designed for SKEKB.
  - Both chambers are same in design except for the diameter of IP duct.
  - IP duct is connected to beam ducts for QCS-magnets (φ20 mm) via crotch duct. (crossing angle is 83 mrad)

- Loss factor ($\sigma_z = 6$ mm)
  
  $k_{type1} = 8.72 \times 10^{-4}$ V/pC  
  $k_{type2} = 7.98 \times 10^{-4}$ V/pC

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![Diagram showing IP chamber types and their corresponding loss factors](image)

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**IP chamber**

- **Impedance**
  - No longitudinally trapped mode is found.
  - Vertical deviation of beam from the center of IP duct excites many TE modes which are trapped in the crotch.
  - Effect of these trapped modes on the beam and IP duct will be investigated.

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**Result of Eigenmode solver**

- \( R_s = 3.9 \times 10^5 \ \Omega/m \)
- \( Q = 4.9 \times 10^3 \)
- \( f_r = 4.8 \times 10^5 \ \text{Hz} \)
## Total loss factor & Power loss (LER)

<table>
<thead>
<tr>
<th>Component</th>
<th>Loss factor [$V/C$]</th>
<th>Number of items</th>
<th>Loss factor (total) [$V/pC$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistive wall</td>
<td>1.03E+09</td>
<td>2200 [m]</td>
<td>2.26</td>
</tr>
<tr>
<td>Cu</td>
<td>7.89E+08</td>
<td>2200 [m]</td>
<td>1.74</td>
</tr>
<tr>
<td>Pumping port</td>
<td>3.65E+02</td>
<td>2200 [m]</td>
<td>8.04E-07</td>
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<td>Flange connection</td>
<td>1.28E+07</td>
<td>2000</td>
<td>0.03</td>
</tr>
<tr>
<td>Bellows</td>
<td>3.00E+09</td>
<td>1000</td>
<td>3.00</td>
</tr>
<tr>
<td>Gate valve</td>
<td>3.00E+09</td>
<td>1000</td>
<td>0.09</td>
</tr>
<tr>
<td>SR mask</td>
<td>1.82E-03</td>
<td>1000</td>
<td>1.82E-12</td>
</tr>
<tr>
<td>Movable mask</td>
<td>2.31E+11</td>
<td>16</td>
<td>3.70</td>
</tr>
<tr>
<td>Taper</td>
<td>3.83E+08</td>
<td>16</td>
<td>6.13E-03</td>
</tr>
<tr>
<td>BPM</td>
<td>1.63E+08</td>
<td>440</td>
<td>0.07</td>
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<td>BxB FB BPM</td>
<td>5.90E+08</td>
<td>10</td>
<td>5.90E-03</td>
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<tr>
<td>FB kicker</td>
<td>5.01E+11</td>
<td>1</td>
<td>0.50</td>
</tr>
<tr>
<td>IP chamber</td>
<td>8.00E+08</td>
<td>1</td>
<td>8.00E-04</td>
</tr>
</tbody>
</table>

### Power Loss: $P_{\text{HOM}}$

- Beam current $I$: 3.6 A
- Number of bunch: 2503
- Circumference: 3016.26 m
- Bunch spacing $T_b$: 4 ns

\[
P_{\text{HOM}} = I^2 k T_b = 910 + \alpha \text{ kW (Al duct)}\]

\[
883 + \alpha \text{ kW (Cu duct)}\]
Summary

- Loss factors and impedances of the components of SKEKB LER were calculated by GdfidL.
  - Pumping port
  - Flange connection
  - Bellows (Gate Valve)
  - SR mask
  - Movable mask
  - Taper
  - BPMs
  - IP duct
- Total loss factor is \( \sim 18 \text{ V/pC} \), and the corresponding power loss is \( \sim 900 \text{ kW} \).

- Next step:
  - Estimation of other components such as injection section, interaction region, etc.
  - Investigation of the effects of the high-impedance components at high frequency on the beam. (bellows, movable mask, etc)
  - Calculation of loss factors and impedances of the components of HER.