COHERENT SYNCHROTRON RADIATION PREDICTED AT THE
SUPERKEKB DAMPING RING

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Abstract

The damping ring (DR) of SuperKEKB is under
construction in order to inject low emittance positron
beam into the main ring. We calculated the bunch
lengthening and the energy spread caused by the
longitudinal wake, which is dominated by the CSR wake
field. The result was within the tolerance level.

INTRODUCTION

The KEKB collider is being upgraded to SuperKEKB in
order to improve the luminosity. The beam energy of the
Low Energy Ring (LER) is 4 GeV for positrons, and that
of the High Energy Ring (HER) is 7 GeV for electrons.
LER injection system consist a 1.1 GeV DR [1, 2] as
shown in Figure 1. Machine parameters of SuperKEKB
DR are shown in Table1. The construction of DR will be
finished in the Japanese FY 2013 and the first beam is
expected in the JFY 2015.

Beam instability is important to design the DR since the
bunch current is relatively high. Since it was found that
the instability due to CSR severely damages the beam
performance for shorter bunch-length and lower
momentum compaction, we tried to found the good shape
of beam pipe and other parameter for suppression of the
instability.

LONGITUDINAL WAKE POTENTIAL

In order to estimate the microwave instability,
longitudinal wake potential per turn has been estimated
for each vacuum component, RF cavity using Gdfidl [3]
with 0.5mm bunch length, which is less than 1/10 of the
natural bunch length. The resistive-wall wake has been
obtained by analytic formula. We chose a design with
antechamber for the DR beam pipe similar to the LER [4]
to reduce the instability caused by the wake field of
vacuum components. And the cross section of beam pipe
is chosen to minimize the microwave instability caused
by CSR.

The antechamber with smaller pipe height shows
better situation since CSR is covered by a beam pipe and
a pipe with small diameter covers to a short wavelength
radiation. We designed the actual cross section of the
beam pipe, considering the easiness of the production as
shown in Figure 2. The wake potential by CSR is
100 times higher than the other components in this case.
In order to reduce the instability, we decided to change
the RF voltage to 1.4MV from 0.261MV and momentum
compaction factor to 0.0019 from 0.0141.

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Figure 1: The schematic layout of positron injection system including the damping ring.

Figure 2: Proposed beam pipe cross section.
Table 1: Damping ring parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Energy</td>
<td>1.1 GeV</td>
</tr>
<tr>
<td>Maximum bunch charge</td>
<td>8 nC</td>
</tr>
<tr>
<td>No. of bunch trains/ bunches per train</td>
<td>2/2</td>
</tr>
<tr>
<td>Circumference</td>
<td>135.5 m</td>
</tr>
<tr>
<td>Maximum stored current</td>
<td>70.8 mA</td>
</tr>
<tr>
<td>Horizontal damping time</td>
<td>10.9 ms</td>
</tr>
<tr>
<td>Injected-beam emittance</td>
<td>1700 nm</td>
</tr>
<tr>
<td>Equilibrium emittance(h/v)</td>
<td>41.4/2.07 nm</td>
</tr>
<tr>
<td>Maximum x-y coupling</td>
<td>5 %</td>
</tr>
<tr>
<td>Emittance at extraction(h/v)</td>
<td>42.5/3.15 nm</td>
</tr>
<tr>
<td>Energy band-width of injected beam</td>
<td>±1.5 %</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.055 %</td>
</tr>
<tr>
<td>Bunch length</td>
<td>6.53 mm</td>
</tr>
<tr>
<td>Momentum compaction factor</td>
<td>0.0141</td>
</tr>
<tr>
<td>Cavity voltage for 1.5 % bucket-height</td>
<td>1.4 MV</td>
</tr>
<tr>
<td>RF frequency</td>
<td>509 MHz</td>
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</tbody>
</table>

Table 2: Bending magnet parameters of DR

<table>
<thead>
<tr>
<th>Bend</th>
<th>Length[m]</th>
<th>Bending angle</th>
<th># of elements</th>
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<tr>
<td>B1</td>
<td>.74248</td>
<td>.27679</td>
<td>32</td>
</tr>
<tr>
<td>B2</td>
<td>.28654</td>
<td>.09687</td>
<td>38</td>
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<td>B3</td>
<td>.39208</td>
<td>.12460</td>
<td>6</td>
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<tr>
<td>B4</td>
<td>.47935</td>
<td>.15218</td>
<td>2</td>
</tr>
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</table>

Figure 3: Longitudinal wake potential caused by vacuum components (a) and CSR (b).

Figure 4: Longitudinal phase space for tracking simulation in DR: (a) Gaussian beam, (b) beam from linac before damping.

CSR EFFECT

We have made multi-particle tracking simulation for Gaussian beam to estimate the degradation of the beam quality through broadening the beam energy spread and lengthening the bunch length with this wake potential. The tracking used up to 5,000,000 macro particles to confirm the convergence in the number of particles. We also checked the tracking result by using the beam shape from linac before damping instead of damped Gaussian beam. The both longitudinal phase space are shown in Figure 4. The tracking result of the beam from linac showed similar behaviour to the case starting from the damped beam.

Figure 5 show the tracking results using the beam from linac. We lowered mesh size until a result converged since the mesh size contributed to a numerical noise. The bunch length becomes 33% longer than the initial bunch length and the energy spread enhances 36% at the...
maximum bunch current. 8 nC is maximum bunch charge which we expect to inject to DR.

We suppose that the impedance peak which caused the peak the energy spread and the bunch length in the different bunch current shown in previous paper [5] is caused by the periodic structure of the lattice of DR that approximately synchronizes with frequency of the eigenmode of CSR. We introduced decrement by the resistance of the wall and simulated again. As the result, the unnatural impedance peak disappeared and the bunch length and the energy spread increase smoothly.

We changed the number of kick per turn in tracking, in order to check that the sensitivity of CSR instability to number of kick per turn. Figure 5 (a) (b) and (c) show the results of single kick per turn, 5 kicks per turn and 30 kicks per turn, respectively. In the case of 30 kicks per turn, the bunch length and energy spread become 10% and 14% larger than initial value and it seems to converge in comparison with 5 kicks case. The many number kick is more realistic than single kick per turn. The importance of number of kick per turn N is related to momentum compaction factor $\alpha$, energy spread $\sigma_\delta$, circumference of ring $C$ and the wave length of instability $\lambda=0.3\text{mm}$. When we calculate $\sigma_\delta \times \alpha \times C/N$ using a DR parameter and $N=30$, it becomes $0.035\text{mm}$. The result shows the following relation.

$$\sigma_\delta \times \alpha \times C/N < \lambda$$

It can explain the simulation results. We expect that the increasing of the bunch length and the energy spread don’t have any problem in real experiment.

**SUMMARY**

We calculated the longitudinal microwave instability effect for SuperKEKB DR. The longitudinal wake is dominated by the CSR wake field and the hexangular antechamber has been proposed as beam pipe based on the calculation result. The bunch length and energy spread won’t enhance so as to cause the problem even though the bunch current will be filled maximum. We already fabricated the beam pipe of normal section of DR in the JFY 2012. We start R&D of a special chamber to measure CSR effect in the DR operation.

**REFERENCES**


Figure 5: Energy spread and the bunch length as a function of the bunch intensity by tracking simulation with linac beam for different number of kick per turn. (a) single kick, (b) 5 kicks and (c) 30 kicks/turn. The red (blue) line shows the energy spread (bunch length).