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.

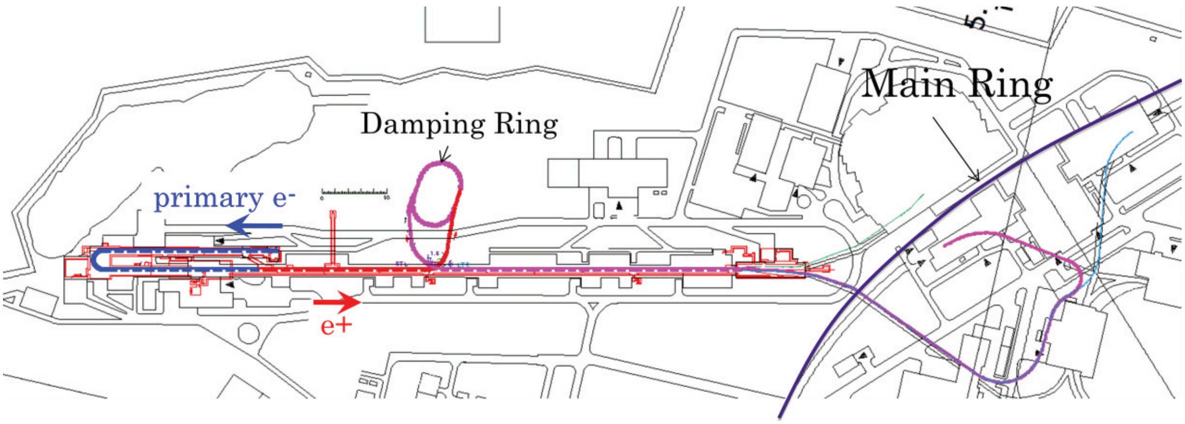

Figure 1: The schematic layout of positron injection system including the damping ring.

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.

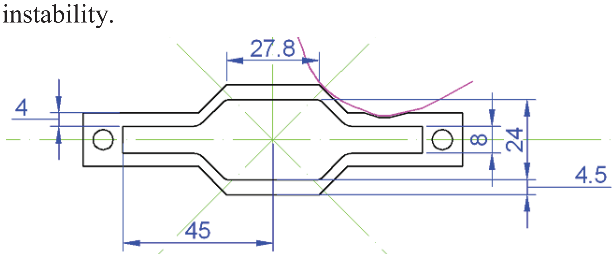

Figure 2: Proposed beam pipe cross section.

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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 calculated by two independent codes [5, 6, 7] and the results agree for rectangular cross section chambers. Figure 3 shows the calculated wake potentials using numerical calculation by Oide's code [8] which is implemented to SAD for the real hexangular antechamber shape. Parameters of dipole magnets which were used for the calculation are tabulated in Table 2. The CSR wake 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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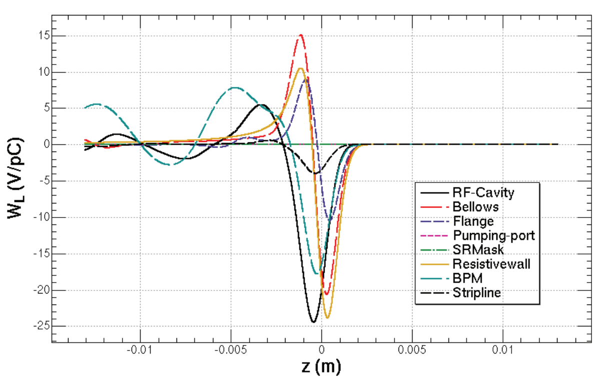
Table 1: Damping ring parameters

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

(a)



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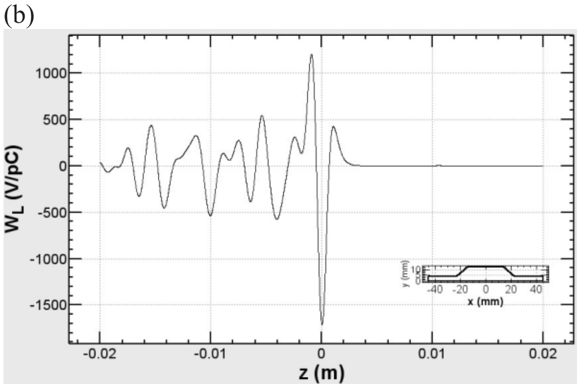
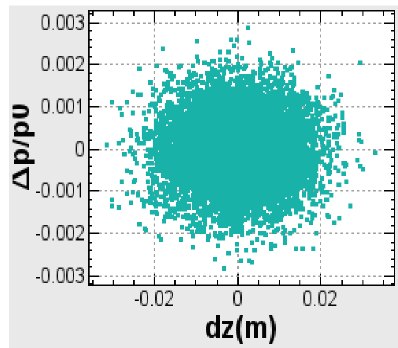


Figure 3: Longitudinal wake potential caused by vacuum components (a) and CSR (b).

Table 2: Bending magnet parameters of DR

Bend	Length[m]	Bending angle	# of elements
B1	.74248	.27679	32
B2	.28654	.09687	38
B3	.39208	.12460	6
B4	.47935	.15218	2

(a)



(b)

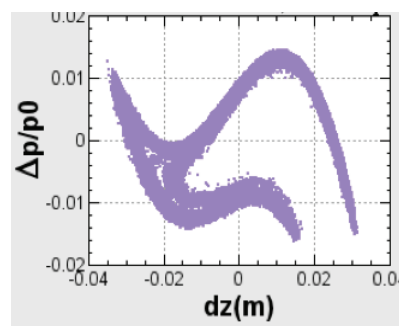


Figure 4: Longitudinal phase space for tracking simulation in DR: (a) Gaussian beam, (b) beam from linac before damping.

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

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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 α, energy spread σ_δ, circumference of ring C and the wave length of instability λ=0.3mm. When we calculate $\sigma_\delta \times \alpha \times C/N$ using a DR parameter and N=30, it becomes 0.035mm. The result shows the following relation.

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

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.

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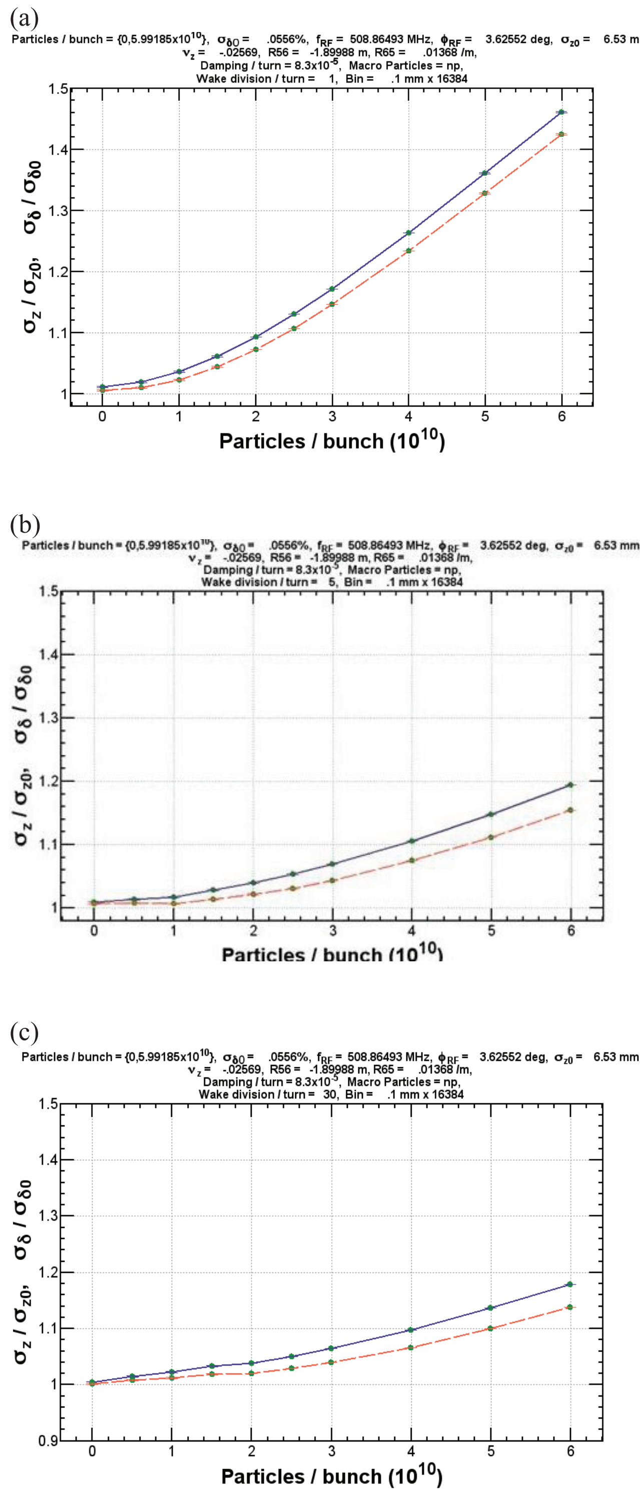

Figure 5: Energy spread and the bunch length as a function of the bunch intensity by tracking simulation with linac beam for different number of kick per turn. (a) single kick, (b) 5 kicks and (c) 30 kicks/turn. The red (blue) line shows the energy spread (bunch length).

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