EFFECT OF COHERENT SYNCHROTRON RADIATION AT THE SUPERKEKB DAMPING RING

Hitomi Ikeda*, T. Abe, M.Kikuchi, K.Oide, K.Shibata, M.Tobiyama and D.Zhou,
KEK, High Energy Accelerator Research Organization, Ibaraki 305-0801, Japan

Abstract

The longitudinal wake field dominated by the coherent synchrotron radiation (CSR) is important in the SuperKEKB damping ring (DR). The peak of the CSR wake field is estimated to be 100 times higher than those of the vacuum chamber components. We have calculated the CSR effect for different vacuum chamber cross-sections, and have adopted the one which most reduced longitudinal instability.

INTRODUCTION

The SuperKEKB is now under construction to get 40 times higher luminosity than KEKB. The beam currents are 3.6 A and 2.6 A for the low energy ring (LER) and the high energy ring (HER), respectively. While the beam current is doubled, the vertical beam size is squeezed to 60 nm at the interaction point to gain 20 times luminosity. DR is necessary to inject the low emittance positron beam to the LER, which has very small acceptance in both of transverse and longitudinal planes [1, 2]. We will construct the DR with the parameters shown in Table 1. The positron beam is accelerated to 1.1 GeV before injected to the DR. A transport line from linac to DR is incorporated with an energy compression system that rotates the longitudinal phase space to compress the energy spread within the energy acceptance of the DR. The bunch length of the extracted beam is compressed with the bunch compression system, which is embodied in the return line. 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 for suppression of the instability.

MICROWAVE INSTABILITY

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. The wake potential by CSR is calculated by two independent codes [5, 6] and the results agree for rectangular cross section chambers. Figure 1 shows the calculated wake potentials using numerical calculation by Oide's code [7] for antechamber. The CSR wake is 100 times higher than the other components in this case. Parameters of dipole magnets are tabulated in Table 2. With this wake potential, 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. 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. And the cross section of beam pipe is chosen to minimize the microwave instability caused by CSR.

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

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

*hitomi.ikeda@kek.jp

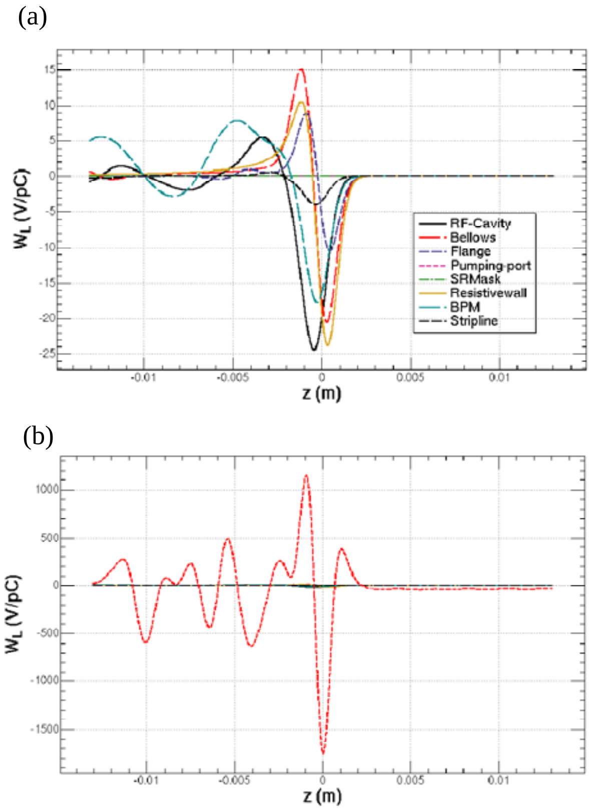

Figure 1: Longitudinal wake potential caused by (a) vacuum components and (b) CSR.

CHAMBER SHAPE

The cross section of DR beam pipe is decided based on the CSR instability. We calculated the wake potential of CSR for several shapes as shown in Figure 2 with the results shown in Figure 3. The tracking result of each CSR is tabulated in Table 3 for 4 nC and 8 nC. 8 nC is maximum bunch charge which we expect to inject to DR. The antechamber with smaller pipe height shows better situation. Because 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, based on (b)-type as shown in Figure 4.

The wake field of CSR was calculated for the designed beam pipe and the tracking simulation was made with results shown in Figure 5. The tracking used up to 5,000,000 macro particles to confirm the convergence in the number of particles. The bunch length becomes 15% longer than the initial bunch length and the energy spread enhances 35% at the maximum bunch current. We also checked the tracking result by using the beam from linac before damping instead of damped Gaussian beam. Figure 5 (b) shows the result. The beam from linac damps to somewhat different state with longer bunch length and wider energy spread compared to the case starting from the damped beam. We found the peak the energy spread and bunch length in the different bunch current for (a) and (b). It may happen that an instability with high frequency mode ($k < 4\pi/\sigma_z$) causes the oscillation of bunch length and energy spread as shown in Figure 6. The emittance fluctuates greatly at the same time. The cycle of emittance change is 10 times of the synchrotron oscillation. This is thought a sort of saw tooth instability. The mechanism of the instability at the point is under consideration.

We have also applied a linearlized Vlasov eigenvalue calculation [8] to confirm the result and get Figure 7, which is more or less consistent with the tracking simulation for energy spread. There is some discrepancy for bunch length.

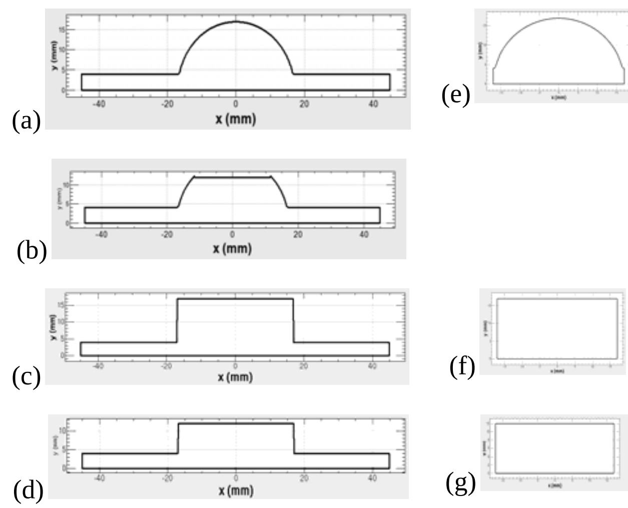

Figure 2: Cross section of beam pipe. (a)-(d) are antechambers and (e)-(g) are normal chambers.

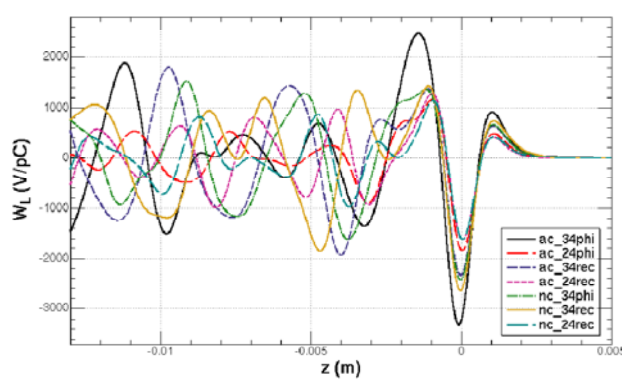

Figure 3: Wake fields of CSR for several beam pipe whose cross section are shown in Figure 2.

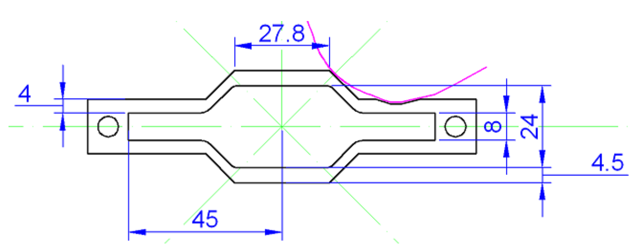

Figure 4: Proposed beam pipe cross section.

Table 3: Enhancement factor of the energy spread and bunch length for several cross sections.

Cross section of beam pipe	$\sigma_\Delta/\sigma_{\Delta 0}$		σ_z/σ_{z0}	
	4nC	**8nC**	**4nC**	**8nC**
(a) Antechamber 34 ϕ	39%	65%	40%	66%
(b) Antechamber 24 mm	15%	43%	15%	43%
(c) Antechamber 34 mm rectangular	63%	98%	63%	98%
(d) Antechamber 24 mm rectangular	20%	44%	20%	44%
(e) Normal chamber 34 ϕ	45%	77%	45%	78%
(f) 34 mm rectangular	39%	115%	39%	115%
(g) 24 mm rectangular	14%	39%	14%	40%

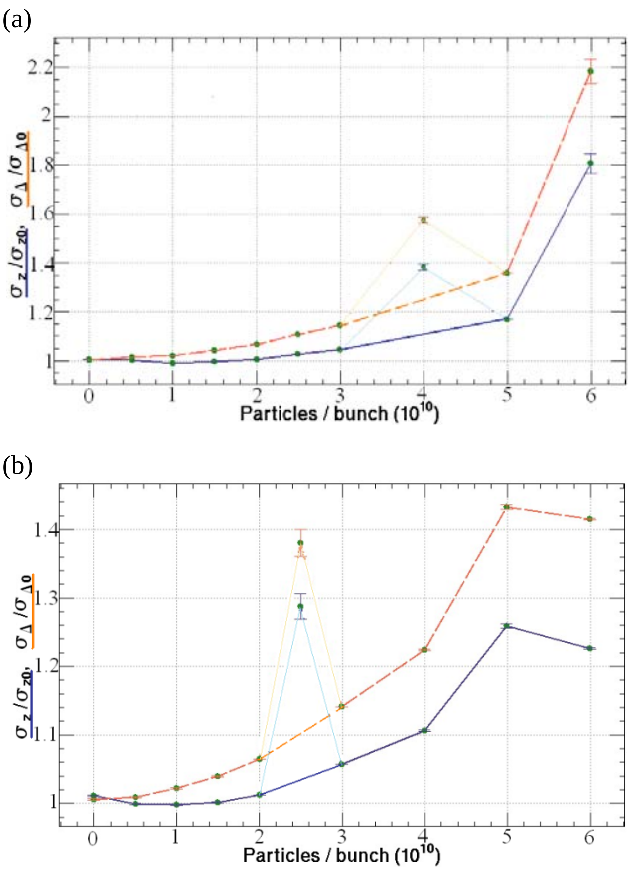

Figure 5: Energy spread and the bunch length as a function of the bunch intensity by tracking simulation with (a) Gaussian beam and (b) linac beam. by using the CSR wake. The red (blue) line shows the energy spread (bunch length).

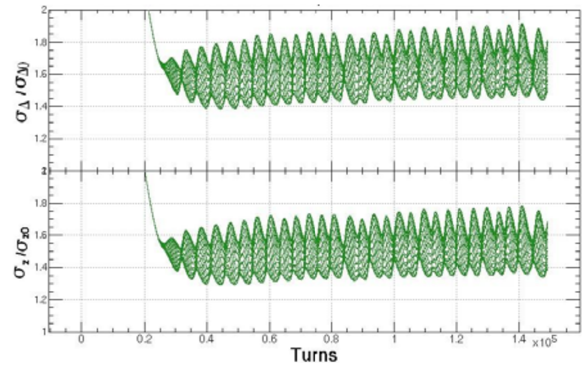

Figure 6: Energy spread and the bunch length as a function of turn with the 3.936 nC linac beam.

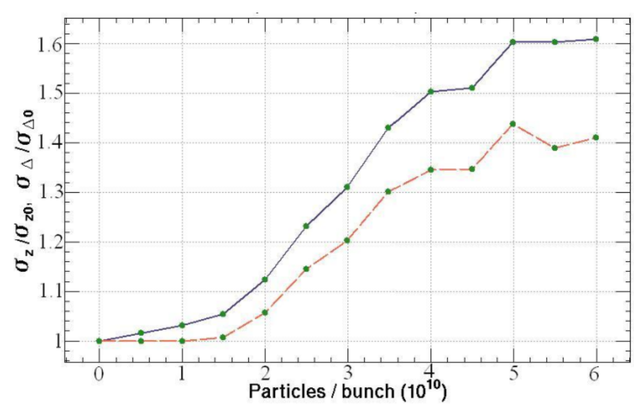

Figure 7: Energy spread and the bunch length as a function of the bunch intensity by linearlized Vlasov eigenvalue calculation.

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. We already started the R&D of prototype, including monitor chamber. Fabrication of chambers is scheduled in the JFY 2012.

REFERENCES

[1] [1] M. Kikuchi et al., Proceedings of IPAC'10, Kyoto, Japan, TUPEB054 (2010).

[2] N. Iida et al., Proceedings of IPAC'11, San Sebastian, Spain, THYA01 (2011).

[3] http://www.gdfidl.de/

[4] Y. Suetsugu et al., Vacuum 84 (2010) 694–698.

[5] D. M. Zhou et al., Proceedings of IPAC'10, Kyoto, Japan, TUPEB018 (2010).

[6] D. M. Zhou et al., Proceedings of IPAC'11, San Sebastian, Spain, MOPS007 (2011).

[7] K. Oide, Proc. PAC'09, Vancouver, BC, Canada, MO3RAI01 (2009).

[8] K. Oide and K. Yokoya, KEK-Preprint-90-10 (1990), K. Oide, Part.Accel. 51 (1995) 43-52.