SLAC-PUB-15169

CSR IN THE SUPERKEKB DAMPING RING

D. Zhou*, K. Ohmi, K. Oide, M. Kikuchi, T. Abe, H. Ikeda, K. Shibata, M. Tobiyama,
KEK/SOKENDAI, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
G. Stupakov, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA

Abstract

Coherent synchrotron radiation (CSR) is generated when a bunched beam traverses a dipole magnet or a wiggler/undulator. It can degrade the beam quality in both storage rings and linacs through enhancing the beam energy spread and lengthening the bunch length, even cause single-bunch microwave instabilities. Using several methods, CSR impedances in the positron damping ring (DR) of the SuperKEKB which is under design were calculated. From the impedances due to CSR, resistive wall and various vacuum components, quasi-Green function wake potentials were constructed and used in simulations of Particle-In-Cell (PIC) tracking. We present the CSR related results in this paper.

INTRODUCTION

In modern storage rings, CSR may be a primary obstacle to achieving ultra-short bunch length, ultra-low emittance, or ultra-high luminosity. During the design of the SuperKEKB, it was found that the beam instability caused by CSR is so significant in the high-current option [1, 2] that it accounts for one of the important factors to changing to the present nano-beam scheme [3]. In the main rings of the nano-beam scheme, the transverse emittance will be reduced by a factor of around 10 and the beta functions at the interaction point (IP) will be strongly squeezed in order to achieve the extremely high luminosity of $8 \times 10^{35} cm^{-2} s^{-1}$. Thus beam currents are not as high as those in the high-current scheme.

Due to the facts of small emittance, high intensity and low Tousheck lifetime in the main rings, a damping ring was proposed for the high energy positron ring of the SuperKEKB for improving the beam injection [4]. The bending radius of the main dipoles in the DR is around 2.44 m, which is even smaller than the LER. Thus there is also a concern about the CSR induced instability in the SuperKEKB DR.

IMPEDANCES AND WAKE POTENTIALS

In the present optical layout design of the SuperKEKB DR, FODO cell with alternating bends is adopted [4, 5]. That is, one of the two bends in a normal cell is reversed in the bending angle. One merit of this FODO lattice is that momentum compaction factor can be adjusted in a large range. In total, 4 types of dipole magnets are used in the DR. And their main parameters are listed in Table 1. As a sum of the absolute values of all dipole magnets, the total bending angle is to be 13.646 rad. With respect to the vacuum chamber, octagon round beam pipe with antechamber is adopted in the dipole magnets. The height of the chamber is 34 mm. And the widths with and without antechamber are 34 mm and 90 mm, respectively.

Table 1: Main parameters for the dipole magnets.

Parameter	B1	B2	B3	B4
Effective length (m)	0.674	0.198	0.301	0.339
Bending radius (m)	2.44	2.04	2.23	2.28
Number	32	38	6	2

Applied with the parameters listed above, the CSR impedances were calculated using three different methods: Agoh and Yokoya's analytical formulae for steady-state CSR in parallel plates [6], Stupakov's code based on parabolic equations [7] and Oides's code based on parabolic equations but with less approximations [2]. In the parallel plates model for steady-state CSR, the distance between the upper and lower plates is set to be 34 mm. In the numerical calculations using CSR codes, the beam pipe is simplified as square-shaped cross section and is uniform in the longitudinal direction. And interference between consecutive magnets is neglected. That is, in field integrations, an infinitely long straight pipe with the same cross-section is always added at the exit of the toroidal pipe. In all three methods, the pipe wall is assumed to be perfectly conductive.

The total CSR impedances are shown in Figure 1. Besides the ultra-low frequency parts, relatively wide discrepancy is seen between the parallel plates model and the numerical calculations. This is due to shielding of the side walls and the transient effects associated with finite length of the dipoles. The impedances obtained by Oide's code have strong oscillating structures at the high frequency parts, but this is not well understood yet. The two codes agree well in low frequency parts where pipe shielding is strong.

The wake potentials of Gaussian bunch with rms length of 0.5 mm were calculated from the CSR impedances, as shown in Figure 2. The main difference between the three methods appears to lie in the tail parts in the range of several σ_z. The wake potentials of various vacuum components, such as ARES cavity [8], bellows, flange gaps, synchrotron masks, BPMs, and stripline kicker, were calcu-

* dmzhou@post.kek.jp

Work supported by US Department of Energy contract DE-AC02-76SF00515.

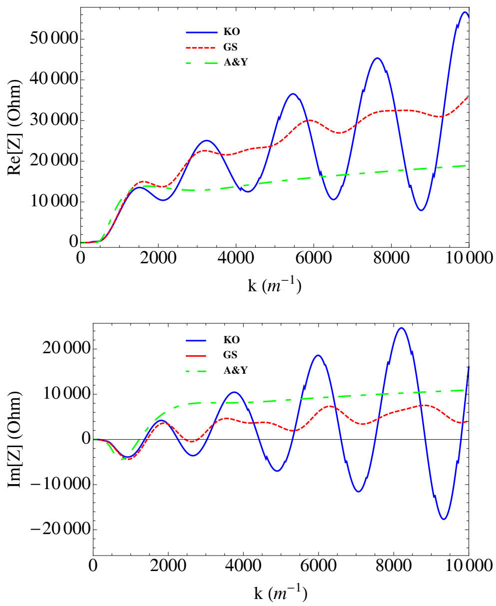

Figure 1: Total CSR impedances calculated by using Agoh and Yokoya's formulae (A&Y), Stupakov's code (GS), and Oide's code (KO).

lated using GdfidL [9]. The impedance of restive wall was calculated using analytical formula [10]. The total wake potential for all vacuum components and resistive wall is shown in Figure 3.

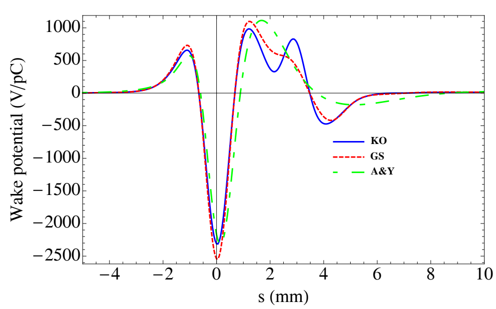

Figure 2: Total wake potentials of CSR with 0.5 mm Gaussian bunch. The head of the bunch is to the left.

SIMULATION RESULTS

A PIC tracking code was developed and used in simulations of microwave instability in the DR. Two versions of the designed optics were studied. The main machine parameters used in the particle tracking are listed in Table 2. The version 1.210 was optimized from version 1.140 for purpose of suppressing strong microwave instability caused by CSR. The simulation results are summarized in Figure 4. In all simulations, we used the CSR wake calculated by Stupkov's code. Clearly, we see that CSR effect is dominant in the present designs of the DR. In version 1.140, tiny sawtooth instability was observed when bunch population went higher than 3×10^{10}. While in version 1.210, beam is always stable with bunch population up to 6×10^{10}.

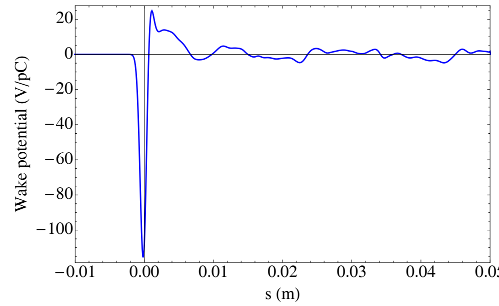

Figure 3: Total wake potential from vacuum components and resistive wall with 0.5 mm Gaussian bunch.

Table 2: Main parameters used in tracking simulations.

Parameter	Ver. 1.140	Ver. 1.210
Beam energy (GeV)	1	1.1
Circumference (m)	135.5	135.5
Bunch population (10^{10})	5	5
RF voltage (MV)	0.5	0.5
Bunch length (mm)	5.1	11.01
Energy spread (10^{-4})	5.44	5.5
Synch. tune	0.00788	0.0152
Damping rateturm (10^{-5})	7.28	8.25
Mom. compaction factor	0.00343	0.0141

INSTABILITY THRESHOLD

In this section we apply Stupakov and Heifets's 1-D model, which was developed for instability analysis of a coasting beam [11] due to CSR, to the DR. This is reasonable because CSR is shown to to be dominant in tracking simulations. Assuming positive momentum compaction, the instability is determined by the dispersion relation

$$1 = -i\frac{4\pi\epsilon_0 c\Lambda}{\sqrt{2\pi}} \cdot \frac{Z(k)}{kC} \int_{-\infty}^{\infty} dp \frac{pe^{-p^2/2}}{\Omega + p} \qquad (1)$$

where $\Lambda = n_b r_0/(\eta\gamma\sigma_{p0}^2)$ and $\Omega = \omega/(ck\eta\sigma_{p0})$, and $Z(k)$ is the total CSR impedance in unit of Ohm. With Gaussian bunch n_b is equal to $N/(\sqrt{2\pi}\sigma_z)$. For detailed definitions of the parameters in Eq. 1, see Ref. [11]. With free space steady-state CSR impedance inputted in Eq. 1, an instability threshold for the bunch population can be derived [12]

$$N_{th} = \frac{\pi^{1/6} F}{\sqrt{2} r_0 \lambda^{2/3}} \qquad (2)$$

where $F = CR^{-1/3}\alpha_p\sigma_{p0}^2\sigma_z$ is a scaling factor determined by realistic machine design. Here we assumed total bending angle of 2π with constant bending radius. For the case of SuperKEKB DR, a constant factor was used for correction in Eq. 2. Eq. 2 indicates that the bunch population

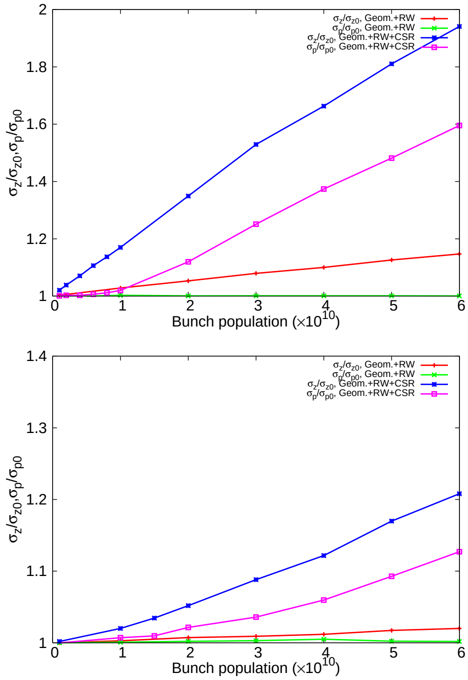

Figure 4: Relative bunch length and energy spread as a function of bunch population with and without CSR. The top and bottom figures correspond to the design versions of 1.140 and 1.210, respectively.

threshold is proportional to F. It implies that we can design a ring with F high enough to avoid CSR induced instability.

The integral in Eq. 1 can be replaced by

$$G(\Omega) = \sqrt{2\pi} + i\pi\Omega e^{-\Omega^2/2}\{1 + \text{erf}[i\Omega/\sqrt{2}]\} \quad (3)$$

where erf[z] is error function. Using Eq. 3 and the CSR impedances given by the free space model, Agoh and Yokoya's formulae for parallel plates, and Stupakov's code, we numerically solved the dispersion relation Eq. 1. The thresholds as a function of the wavelength are depicted in Figure 5. With respect to version 1.140, the S-H theory quite agrees with tracking simulations. For the version 1.210, the S-H theory predicts threshold higher than the design goal, while increase of energy spread due to CSR is still observed in simulations (see Figure.4). It indicates that the S-H theory works well when CSR instability is strong enough.

SUMMARY

CSR impedances and conventional wake potentials in the SuperKEKB DR were calculated and applied in PIC tracking simulations. The simulation results suggest that CSR may be dominant in the impedance sources at the DR. And it is confirmed by the instability analysis based on 1-D Vlasov equation. The instability analysis provides a criteria for optimization of the DR optics to avoid CSR instability. More careful calculations of the CSR impedances, taking into account the interference between consecutive bends and the fringe field effects, are undergoing.

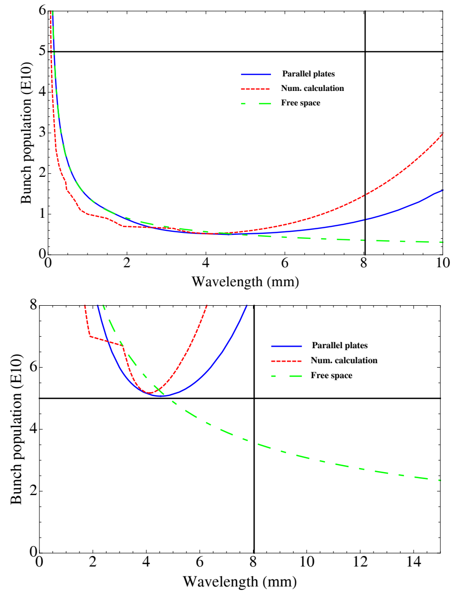

Figure 5: The CSR threshold as a function of the wavelength. The blue solid, red dashed and green dash-dotted lines are the results of CSR impedances given by A&Y formulae, Stupakov's code, and free space model, respectively. The vertical straight line is the approximate shielding threshold due to parallel plates calculated by $2\sqrt{b^3/R}$. The horizontal straight line denotes the designed bunch population. The top and bottom figures correspond to the design version 1.140 and 1.210, respectively.

The author D.Z. would like to thank Y. Cai and T. Agoh for valuable discussions.

REFERENCES

[1] T. Agoh, PhD thesis, 2004.

[2] K. Oide, presentation at KEKB ARC 2009.

[3] H. Koiso, et al., these proceedings.

[4] M. Kikuchi, et al., these proceedings.

[5] M. Kikuchi, et al., PAC05.

[6] T. Agoh and K. Yokoya, Phys. Rev. ST Accel. Beams 7, 054403 (2004).

[7] G. Stupakov and I. Kotelnikov, Phys. Rev. ST Accel. Beams 12, 104401 (2009).

[8] T. Abe, et al., these proceedings.

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

[10] A. Chao, Physics of Collective Beam Instabilities in High Energy Accelerators, Wiley (1993).

[11] G. Stupakov and S. Heifets, Phys. Rev. ST Accel. Beams 5, 054402 (2002).

[12] J. Byrd, et al., Phys. Rev. Lett. 89, 224801 (2002).