STUDY FOR ILC DAMPING RING AT KEKB

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Abstract

ILC damping ring consists of very low emittance electron and positron storage rings. It is necessary for ILC damping ring to study electron cloud effects in such low emittance positron ring. We propose a low emittance operation of KEKB to study the effects.

INTRODUCTION

KEKB has been operated as a B factory and accumulated the integrated luminosity of 850 fb^{-1} at the summer of 2008. Electron cloud issues, which had been serious at KEKB, were overcome and the world record luminosity 1.7×10^{34} cm^{-2}s^{-1} was achieved. Trains of positron bunches are stored with arbitrary length and spacing in the KEKB low energy ring. Solenoid magnets to protect and control the electron cloud are powerful to study of the effect. KEKB can be used for an accelerator research of ILC damping ring.

KEKB has already been used for several studies for the ILC. Studies on electron clouds are crucial for the ILC as well as Super B factories. KEKB has studied electron cloud issues by observing the beam size blowup and associated head-tail motion, measuring the amount of cloud with several types of dedicated devices, installing beam pipes with various shapes and surface treatments, estimating the secondary electron yield (SEY) by looking at the amount of cloud vs. beam current, and measuring SEY with a special in-situ apparatus to bare samples of surface to the beam. The next generation bunch-by-bunch feedback system developed under US-Japan collaboration is also a common technology for the ILC and Super B, and has been applied to the KEKB beam.

LOW EMITTANCE OPERATION

A major difference between the damping ring and KEKB is the emittance. The emittance of the damping ring is 0.5 nm, while that of KEKB is 18 nm. Thus the emittance make lower from 18 nm to 2 nm with a lower energy operation from 3.5 GeV to 2.3 GeV. The magnetic field of all components are scaled down to 2.3 GeV, including the wigglers and the Belle solenoid. The optics of the ring for the study is shown in Fig. 1. Similar plan is in progress at CESR in Cornell Unversity. Table 1 shows parameter list of KEKB, CESR and ILC damping ring.

Unlike the ILC–DR, the study mode of the KEKB–LER suffers from the emittance blow-up due to intrabeam scattering, as the beam energy is much lower. The equilibrium emittance is a function of the number of particles per bunch and the vertical / horizontal emittance ratio, i.e., coupling. Figure 2 shows the equilibrium emittance with intrabeam scattering as functions of particles / bunch for two coupling ratios.

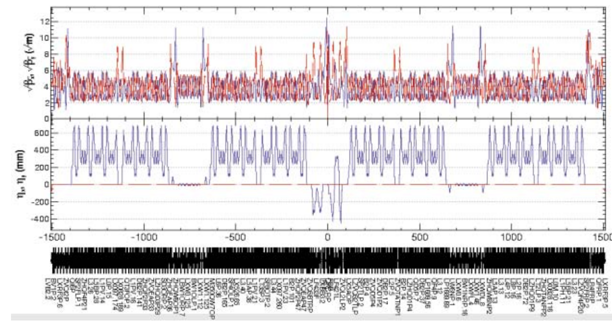

Figure 1: The beam optics of the LER of KEKB for the study, showing $\sqrt{\beta_{x,y}}$ and $\eta_{x,y}$ in upper and lower rows, respectively. Belle is located in the middle of the line.

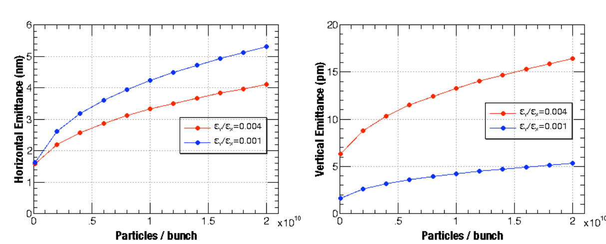

Figure 2: Horizontal (lfet) and vertical (right) equilibrium emittances vs. particles/bunch with intrabeam scattering, for two emittance ratios.

As the beam energy of the KEKB–LER for this study is very low, the space charge effect is much larger than the ILC–DR. The vertical tune shift due to space charge is $\Delta\nu_y \approx 0.035$ with $N = 2 \times 10^9$ and 0.4% coupling. At higher intensity, the space charge effect is somewhat relaxed by the emittance growth due to intrabeam scattering, with the result that the vertical tune shift is $\Delta\nu_y \approx 0.15$ with $N = 2 \times 10^{10}$, where the vertical emittance increases to $\varepsilon_y = 17$ pm.

In order to realize the low emittance in KEKB-LER, the optics should be corrected in an appropriate way as well as a closed orbit distortion(COD). The goal for a ratio of the vertical emittance to the horizontal is 0.2% in this study.

Table 1: Basic parameters of the ILC damping ring

Lattice		KEKB	KEKB-DR	Cesr-TA	ILC-DR	PEP-II
circumference	L(m)	3,016	3,016	768	6,414	2200
energy	E	3.5	2.3	2-5	5.0	3.1
bunch population	$N_+(10^{10})$	8	2	2	2	8
emittance	ε_x(nm)	18	1.5	2.3	0.5	48
momentum compaction	$\alpha(10^{-4})$	3.4	2.4	64	4.2	
bunch length	σ_z(mm)	6	4.2	6.8	6	12
rms energy spread	$\sigma_E/E(10^{-3})$	0.73	0.48	0.86	1.28	
synchrotron tune	ν_s	0.025	0.011	0.098	0.067	0.025
damping time	τ_x	40	150	56.4	26	

The KEKB-LER lattice includes machine errors and BPM errors are evaluated by using SAD [1, 2].

The machine errors consist of a magnet alignment error from a design orbit and a field gradient error. The BPM errors consist of a jitter error (resolution of measurement-by-measurement) and an alignment error from the design orbit. The errors are assumed to obey a Gaussian distribution. The BPM system is an averaged measurement which is not a single-pass BPM.

The major source for the emittance dilution will be the orbit distortion in the sextupoles. Their sensitivities obtained by the model are shown in Fig. 3. According to Fig. 3, the orbit distortion of the sextupoles should be better than 150 μm to achieve the vertical emittance below 10 pm.

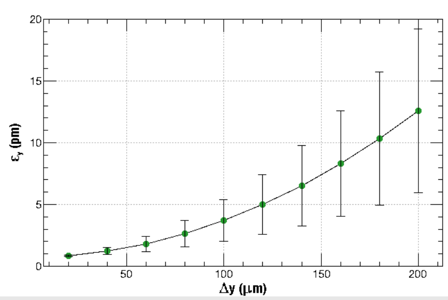

Figure 3: The sensitivity of the vertical emittance to the vertical misalignments of sextupoles. The horizontal axis is the r.m.s. value of vertical offsets randomly given to all sextupoles with Gaussian distribution. The error bars are the statistical errors for twelve samples. Intrabeam scattering is not included.

The machine errors considered in the simulation study are 100 (Quadrupole) and 200 μm (Bend, Sextupole) in the transverse position, and 0.1 (Bend) and 0.2 mrad (Quad and Sext) in the x-y rotation angle. Errors of the strength are 0.05% (Bend), 0.1% (Quad) and 0.2% (Sext).

The COD is corrected by using 166 BPMs in the horizontal plane and 208 BPMs in the vertical plane. The optics measurement is performed by fitting of a response matrix for a single kick orbit or a change of rf frequency in principle. The xy coupling and dispersion function are corrected by local bumps at sextupoles.

In order to achieve the emittance ratio of 0.2% and/or the orbit distortion in the sextupoles, the BPM resolution should be less than 20 μm. The alignment error is not sensitive to a performance of the optics corrections.

In KEKB, the BPM resolution and alignment error are estimated to be less than 10 μm and 40 μm, respectively. The alignment error may be larger due to vacuum chamber movement due to a thermal stress, but is expected to be less than 200 μm [3, 4].

The KEKB tunnel floor vibration near the IP has been measured along with the vibrations of several magnets. The floor vibration presents a peak at around 13 Hz and its integrated amplitude in the frequency range above 10 Hz is about 10 nanometers. The magnets vibrate with larger amplitude at their specific frequencies, sometimes as large as 0.1μm at 10 Hz. This might become a problem when trying to achieve an emittance which is ten times smaller than that of KEKB [5].

The dynamic aperture is estimated by numerical tracking simulations using SAD. The horizontal amplitude of the injected beam is 7.5×10^{-6} m and 1.2×10^{-6} m for the vertical at 2.3 GeV. An energy aperture is required to be larger than $\pm0.25\%$. The requirement of the dynamic aperture is satisfied enough for the injected beam.

ELECTRON CLOUD INSTABILITY

Coupled bunch instability does not depend on the emittance. In the very low emittance ring, single bunch effects is mainly concerned. Electrons near the beam move frequency comparable or higher than that corresponding to the bunch length. The frequency of electrons near the beam is expressed by

$$\omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}. \qquad (1)$$

where λ_p is the line density of the bunch. Electrons oscillate with an phase angle $\omega_e\sigma_z/c \geq 1$ along the bunch. The single bunch instability is caused by a wake effect with the

Table 2: Threshold of the ILC damping ring and other rings

		KEKB	KEKB	KEKB-DR	Cesr-TA	ILC-DR	PEP-II
bunch population	$N_+(10^{10})$	5	8	2	2	2	8
bunch spacing	ℓ_{sp}(ns)	8	7	6	14	6	6
electron frequency	$\omega_e/2\pi$(GHz)	28	40	84	80	100	15
phase angle	$\omega_e\sigma_z/c$	3.6	5.9	15.9	15.0	12.6	3.7
threshold	ρ_e (m^{-3})	0.63	0.38	0.096	2.92	0.19	0.77

high frequency. The threshold of the fast head-tail instability is given by

$$\rho_{th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_e\beta L} = \frac{\gamma\alpha\omega_e\sigma_\delta/c}{\sqrt{3}\pi KQr_e\beta}. \qquad (2)$$

where $Q = \min(Q_{nl}, \omega_e\sigma_z/c)$ and $K = \omega_e\sigma_z/c$. Q_{nl}, which is the quality factor of the nonlinear beam-electron interaction, is considered to be ~ 7 from the comparison with the numerical simulations.

In the very low emittance rings, the phase angle is very high $\omega_e\sigma_z/c \gg 1$. The threshold depends on the inverse of the phase angle for a small value, while it does not depend on the phase angle larger than Q_{nl}. The threshold is linear of the momentum compaction factor.

The threshold for KEKB, its low energy operation, Cesr-TA and ILC-DR are shown in Table 2.

The purpose of the machine study using the existing accelerators is whether the cloud density is achieved to be less than the threshold and whether the threshold agree with the prediction for the damping ring.

The integrated electron density along the ring determines the instability charcteristics. The electron cloud density should be measured in every typical components. The density is controlled by filling pattern of the bunch train and solenoid magnets to study threshold behavior. The threshold in the study machines should be compared with the estimation for various beam parameter conditions; energy and emittance. Tune shift can be an indicator of the integrated density.

The coherent instability dominates in the present KEKB. The momentum compaction factor of Cesr-TA is very high. This suppresses the fast head-tail instability. Below the threshold of coherent instability, incoherent emittance growth due to nonlinear beam-cloud interaction may be observed. The incoherent emittance growth is more visible for high α machine.

DISCUSSIONS

We discuss advantages and disadvantages to use KEKB for the study of the ILC–DR compare than Cesr-TA and KEK–ATF. The size of the ring, 3 km, is closer to the ILC–DR than other rings such as CESR or KEK–ATF. Momentum compaction factor of KEKB, which is most important control parameter for instabilities, is similar that of ILC–DR. KEKB has operated for eight years delivering high luminosity to Belle. The machine, orbit, and optics have been understood and controlled quite well. Online optics modeling and diagnostic tools has been well developed and should be usable to this study. The KEKB–LER is equipped with solenoid windings of about 2,200 m in its free space to control the electron cloud. It will contribute to the study of the electron cloud by changing various parameters related to the cloud. The measurement of pm vertical emittances is just beyond the reach of the present KEKB beam instrumentation system. An x-ray imaging system, such as is currently under development (see elsewhere these proceedings [6]), would be required.

It is not clear that the tunnel and the ground of KEKB are stable enough to achieve the small emittance. Because of the lower energy and longer damping time, any beam instabilities will appear stronger than the ILC–DR, as well as the intrabeam scattering and the space charge effect. KEKB is being used as B factory machine. Dedicated machine study time is limited.

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