UPGRADE PLAN OF KEKB

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For the KEKB upgrade team

Abstract

The KEKB accelerator has been achieved the luminosity larger than the design value, 10^{34}, and it is finding a way to an upgrade plan of KEKB. The target of the upgrade is a high luminosity that increases by a factor 10 to 30 from the present luminosity. In this report, a strategy and a design of the upgraded KEKB are presented.

INTRODUCTION

Roadmap of KEK, the near-term future program of KEK, has been presented in January, 2008[1]. In the framework of the KEK's roadmap, the KEKB will be shutdown in 2009 and upgraded to achieve a higher luminosity by a factor 30 and more than the present KEKB. The preliminary target luminosity is 5×10^{35} cm^{-2}s^{-1} at the upgraded KEKB.

Recently, crab cavities have been developed and installed in KEKB. The crab cavity realizes an effective head-on collision, although it is a finite-angle crossing of 22 mrad at IP. The head-on collision can resolve a coupling of x and z directions of a particle motion within a colliding bunch. When a horizontal betatron tune is closer to the half integer, a particle motion in the y direction becomes symmetric for x and $-x$ positions of the particle that is a turn-by-turn position. This half-integer tune technique can resolve a coupling of x and y directions. Consequently, the three-dimensional motions becomes the one-dimensional motion when the crab crossing and the half-integer tune technique are adopted as a collision scheme. A beam-beam interaction is a nonlinear force and generates chaotic phenomena in general. However, particles result in a tracking simulation of a circular collider, for instance several thousand turns, are confined within a near-integral surface(KAM) in the phase space. The particle trajectories do not diverge in the case of the one-dimensional motions with the beam-beam interaction, though a "chaos" appears as increasing the beam-beam force. On the other hand, the nonlinear force with multi-dimensional system makes the beam blow-up. If the system becomes one-dimensional and avoids bad resonances, the beam-beam parameter can be increased with increasing beam currents. Therefore, the crab crossing scheme can improve the luminosity much higher than the geometrical gain of the overlap region[2]

The schedule for the KEKB upgrade is restricted in the KEK's roadmap and it is very tight. The baseline is a high current scheme(HC)[3] for the KEKB upgrade. On the other hand, extremely low emittance and low beta function at IP(LELB) with a large Piwinski angle has been proposed at the SuperB project[4, 5]. The LELB scheme can make bunch length longer then the HC scheme and can realize a high luminosity at relatively lower beam currents. A crab waist scheme[6] will be adopted to the LELB scheme at SuperB and can mitigate bad betatron coupling resonances. The crab waist scheme utilizes a sextupole pair which is located at a betatron phase advance of $n\pi$ in the horizontal and $(n/2)\pi$ in the vertical plane from IP. The crab waist can improve the luminosity by a factor of two approximately than that without the crab sextupoles. The crab waist scheme has been tested in DAΦNE at Frascati[7]. We consider the LELB scheme and the crab waist as an alternative scheme when a feasibility of the crab waist will be proved at the real machine.

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HIGH CURRENT SCHEME

The machine parameters of the KEKB upgrade are shown in Table 1. The beam energy with the boost factor

Table 1: Machine parameters.

	LER	HER	unit
E	3.5	8	GeV
I_b	9.4	4.1	A
N	1.18×10^{11}	5.13×10^{10}	
n_b	5018		
ε_x	12		nm
$\varepsilon_y/\varepsilon_x$	0.5		%
β_x^*	20		cm
β_y^*	3		mm
σ_z	3		mm
θ_x	30→0		mrad
ξ_x	0.272		
ξ_y	0.295		
R_L	0.86		
R_{ξ_x}	0.98		
R_{ξ_y}	1.11		
L	5.5×10^{35}		cm^{-2}s^{-1}

is determined by physics requirements so as to be sensitive against both of a new physics such as $B\to\tau\nu$ and time dependent CP violations, for instance $B\to\phi K^0$, $J/\Psi K^0$, in principle. From a point of view to reduce a power consumption, we also should consider to optimize the beam energy for each ring with keeping the center of mass energy. Since a bending radius of the HER dipole magnet is much longer than those of LER, the power loss due to a synchrotron radiation(SR) is less dependent on the beam energies in KEKB. The relation between the SR power and the luminosity is expressed by

$$P_{rad} = U_0 I = \frac{2T_0 E I}{\tau_x} \propto \frac{L}{\tau_x}, \quad (1)$$

where U_0 is a energy loss per one turn, T_0 is a revolution time, and τ_x is a transverse damping time. The longer damping time with keeping the luminosity can save the power consumption, however, shorter damping time is preferable to achieve the higher luminosity. In spite of this, we will choose give up wigglers in LER to make the same damping time in HER rather than changing the beam energy to reduce the power consumption. To compensate the different damping time between LER and HER, the emittance in HER is adjusted to realize a equilibrium condition of colliding bunches.

The emittance is 12 nm which is almost the minimum value determined by the present magnet configuration in the arc section. This low emittance improve the luminosity by 30 % compared with 24 nm. The beta function at IP is 20 cm in the horizontal and 3 mm in the vertical plane, respectively. The bunch length at a zero current is also 3 mm to make hour-glass effect small as much as possible. The horizontal crossing angle at IP is 30 mrad, however, an effective head-on crossing can be realized to adopt crab cavities.

In order to carry out the KEKB upgrade, the facility has to be shut down for three years. The beam pipes of both rings have to be replaced by new ante-chambers to achieve the extremely higher beam currents. In addition, the beam optics in the vicinity of the interaction point will be modified to squeeze the beta function at IP. We have designed the new QCS final focusing magnet with the compensation solenoid and special quadrupole magnets in the interaction region(IR) so as to realize the strong focusing. A positron damping ring is necessary to accomplish the increase of the beam current and the strong focusing at IP. The positron damping ring provides good-quality and high-intensity positrons to the LER ring.

After the modification and the replacement of components in KEKB, the beam operation will be resumed. During the operation, an upgrade and reinforcement of the RF system, the cooling and the electric facilities are carried out. We also continue to develop new crab cavities that can be operated at the high beam current of 10 A. After completion of the upgrade, the luminosity of 5.5×10^{35} $cm^{-2}s^{-1}$ will be achieved. This luminosity estimation is obtained from a strong-strong beam-beam simulation[8]. Figure 1 shows the expected peak and integrated luminosity, beam currents as a function of a fiscal year.

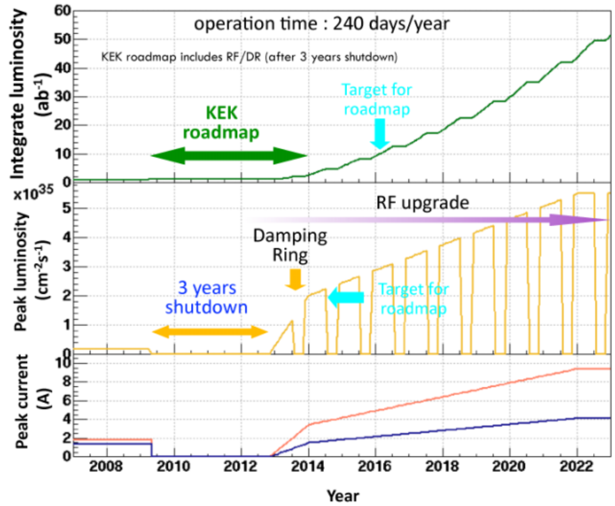

Figure 1: Projected luminosity.

to be 12 nm, a range of the momentum compaction is $0 < \alpha_p < 7 \times 10^{-4}$ in LER and $1 \times 10^{-4} < \alpha_p < 8\times^{-4}$ in HER, respectively. The lattice parameters are shown in Table 2.

Table 2: Lattice parameters.

	LER	HER	unit
ε_x	12		nm
β_x^*	20		cm
β_y^*	3		mm
σ_z	3		mm
V_c (RF)	12	17.4	MW
α_p	1.9×10^{-4}	1.4×10^{-4}	
ν_s	-0.0231	-0.0157	

Further low emittance, 2.2 nm can be achieved in only LER when the dipole magnets are replaced with 4 m long magnets. The length of the present magnet is 0.9 m. The emittance becomes the similar level to that of SuperB. Therefore, a partial super-bunch collision scheme can be possible in the upgrade.

Another advantage of this lattice is that a nonlinear kick due to a sextupole magnet for on-momentum particles can be compensated by another sextupole magnet which is a relation of $-I'$ transformation while a chromatic effect can be collected. Therefore, a larger transverse dynamic aperture can be expected in the lattice by optimizing a magnetic field strength of sextupoles. On the other hand, these sextupoles are utilized to correct optics such as x-y couplings, dispersion functions, beta functions in a positive way. In order to generate a quadrupole and/or skew element, sextupole movers to provide a beam offset and/or an auxiliary coil additional to a main coil of the sextupole magnet are used.

Figure 2 shows a dynamic aperture in LER. There are 54(52 in HER) families of sextupoles in LER. With opti-

OPTICS

The magnet configuration for the upgrade is based on KEKB. The same arc lattice of 2.5π non-interleaved sextupole scheme is used. A flexibility of the lattice is large and a emittance and a momentum compaction can be adjusted independently. When the arc emittance is chosen

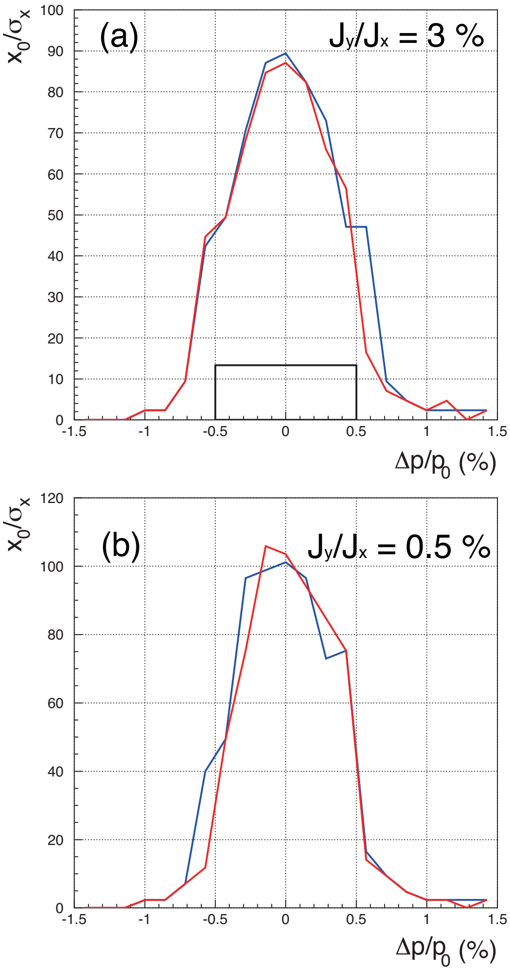

Figure 2: (a) Dynamic aperture for the injected beam in LER. Rectangle shows the requirement for the injection aperture (hard edge of 2σ of the injected beam). (b) Dynamic aperture for the storage beam in LER. The ratio of the initial action variable is the same as the coupling parameter of the ring. Blue line indicates no machine error, red line indicates optics corrections for the machine error.

mizing sextupole magnets, the dynamic aperture is investigated by using a particle-tracking simulation in SAD[9]. In the tracking simulations, a misalignment(vertical) of the beam-line is assumed as a machine error. For instance, the maximum discrepancy of the tunnel level from the reference point is -14 mm. These deformation of the beam-line away from the flat surface affects the optics although a closed orbit distortion is corrected. Consequently, the coupling($\varepsilon_y/\varepsilon_x$) deteriorates to be 0.75 % due to the machine error and the luminosity will be degraded. In order to improve a lattice performance, optics corrections such as x-y couplings, dispersion, and beta functions are performed. The optics correction can reduce the coupling parameter less than 0.1 % which comes from the beam-line distortion.

A positron damping ring is assumed for the injection in LER. In Fig. 2(a), the rectangle shows the requirement from the injected beam and the initial ratio of the vertical action variable to the horizontal is 3 % that is determined by emittances and an injection error. The dynamic aperture satisfies the injection requirement. For the storage beam, Touschek lifetime at 9.4 A and 0.5 % coupling is estimated to be 17 min which comes from the off-momentum dynamic aperture. However, Touschek lifetime becomes to be about 150 min which is longer than the luminosity lifetime of 81 min since a beam size changes due to a dynamic effect and a blow-up from a beam-beam interaction.

IR DESIGN

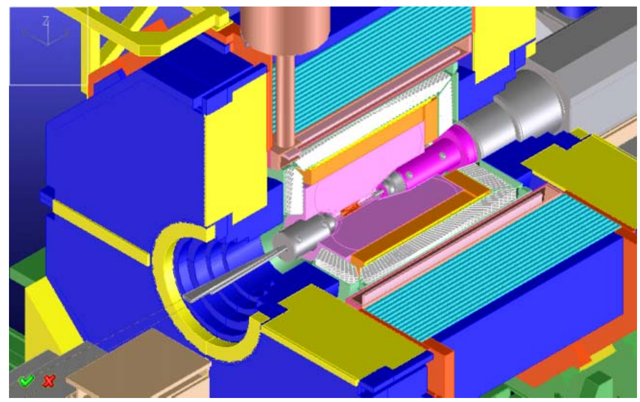

Figure 3: Interaction region.

The final focus quadrupole magnets are placed as close as possible to IP to reduce chromatic effects and the maximum beta function in the vicinity of IP. Figure 3 shows a cut view of the QCS magnet and the detector. The layout of the IR magnets is shown in Fig. 4. The solenoid field of the detector is compensated with anti-solenoids on each side of IP. The integrated field of the solenoids should be

$$\int B_z ds = 0. \tag{2}$$

The remaining x-y couplings and dispersion functions are corrected to be zero at IP and localized in IR by using skew quadrupole magnets and horizontal and vertical dipole magnets in IR. The crossing angle of 30 mrad is adopted to separate two beams in IR. A local chromaticity correction is adopted in LER. We also consider the local chromaticity correction for HER to keep a larger dynamic aperture.

A physical aperture and synchrotron radiation(SR) fans are estimated by a beam size that includes a dynamic emittance and a dynamic beta due to a beam-beam interaction. The dynamic effect depends on a betatron tune and a beam-beam parameter. We assume that the horizontal betatron tune(fractional part) is 0.505 and the horizontal beam-beam parameter is 0.27 as the nominal values. The horizontal beta function becomes the maximum value at QC2 that is the horizontal focusing magnet at the closest to IP. When $5\sigma_x$ beam size at QC2 is required, 100 mm for the nominal beta function of 20 cm at IP and 75 mm for 40 cm are

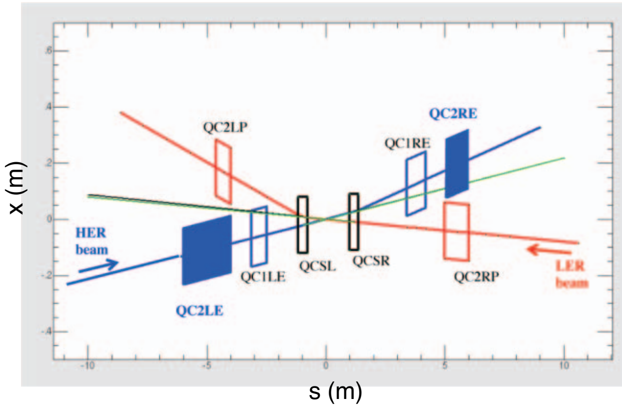

Figure 4: QCS and special IR magnets.

needed as the physical aperture. We also consider SR fans with $3\sigma_x$ beam size. A spread of the SR fan is large in QC2(L) that locates the left side of IP. Introducing a offset of QCS from the design orbit, it makes the SR fan small significantly. Further, the larger horizontal beta function makes the SR fan small. If there is unexpected difficulties to handle the SR fan, we might choose 40 cm as the nominal horizontal beta function at IP. In this case, the luminosity deteriorates by about 20 %.

VACUUM SYSTEM

Copper beam pipes with ante-chambers[10] are adopted for the arc section. Benefits of the ante-chamber are a low SR power density, a low photoelectrons around a positron beam, and a low beam impedance. Figure 5 shows a schematic view of the ante-chamber. The ante-chamber consists of a beam chamber and a SR chamber. The nominal radius of the beam chamber is 45 mm and the height of the SR chamber is 15 mm. A NEG pump is installed in a channel which is the same structure of the SR chamber at the opposite side. The NEG channel is separated by a slit for a RF shield from the beam chamber. Cooling channels are attached at both side of the SR chamber and the NEG chamber.

Figure 5: Ante-chamber.

New bellows are adopted to connect beam pipes for each other. We call this new component a comb-type bellows. The features of the comb-type bellows are a low beam impedance and a high thermal strength. Figure 6 shows a temperature of bellows as a function of the beam current. The temperature of the comb-type bellows is lower than a conventional finger-type bellows by a factor of two. The comb-type bellows can be adopted to a complex shape such as the ante-chamber. However, an accurate alignment of the beam pipes is needed since there is a less flexibility.

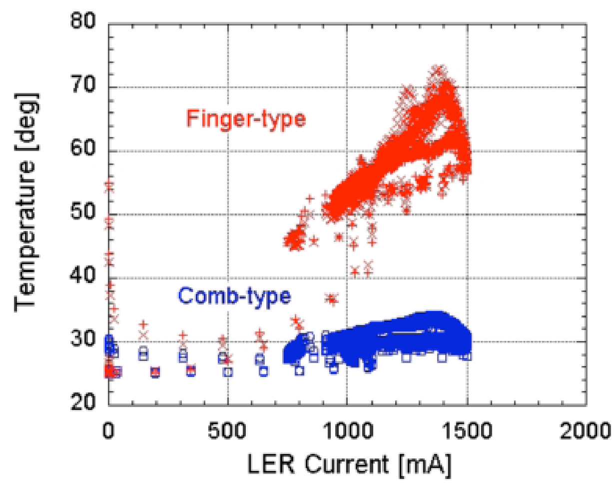

Figure 6: Temperature of bellows.

The high current and the short bunch length imply not only an intense SR power and a higher HOM heating but also an instability due to a coherent synchrotron radiation(CSR). In order to handle CSR, a smaller radius of the beam pipe is effective to suppress the instability. Therefore, we also consider the ante-chamber with a radius of 25 mm. For the small aperture of the beam pipe, the impedance and the pumping availability should be evaluated. We still continue the CSR calculation that is complicated due to an interference of the other impedance of the ring. If the small aperture of the beam pipe is not available due to some difficulties, we will choose longer bunch length of 4 mm. In the case of 4 mm bunch length, the CSR instability can be suppressed significantly and the luminosity will deteriorate by 16 % that is obtained from computer simulations.

CRAB CAVITY

The new crab cavity that can be adopted for the 10 A beam current has been developed for the KEKB upgrade. We consider two candidates for the crab cavity. One is a coaxial type, the other is a wave-guide type crab cavity. The different structures are used for the lower order mode(LOM) damping. Figure 7 shows a schematic view of the crab cavity The detail description can be found in elsewhere[11]. One or two crab cavities are installed for each ring to provide the appropriate crab kick. In the crab crossing scheme, these cavities are located at Nikko section where the superconducting acceleration cavities(SCC) are

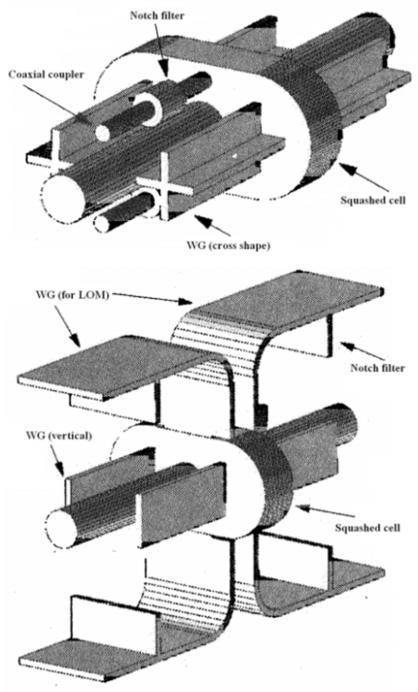

Figure 7: Upper: coaxial type, lower: wave guide type crab cavity.

also located in HER. Therefore, this scheme is similar to the present KEKB and the crabbing mode is not localized in the IR.

SUMMARY

The target luminosity of the KEKB upgrade is 5×10^{35} $cm^{-2}s^{-1}$ or higher for the KEKB upgrade. The baseline is the high current scheme. The design of the vacuum system is almost completed except for the IR chamber. Proto-type of the ante-chamber and the comb-type bellows, and so on have been tested at the present KEKB. However, the CSR evaluation has not done yet. In the IR design, there are still things to be fixed, especially, cure of the SR fan and the design of the beam pipes.

The items of the KEKB upgrade and the luminosity gain are shown in Table 3. During the 3 years shutdown, the replacement of the beam pipe and the modification of the IR will be done at least. Then, the damping ring will be installed and the beam current will be increased gradually. However, the upgrade scenario is strongly dependent on the budget accepted by the Japanese government and international collaborations interested in the flavor physics.

Table 3: Items for the KEKB upgrade.

Item	**Gain**	**Purpose**
beam pipe	1.5	HC, short σ_z, EC
IR	1.5	squeeze β^*
low ε_x & $\nu_x \to$0.5	1.3	mitigate nonlinear effects
crab crossing	2	mitigate nonlinear effects
RF/infrastructure	3	HC
DR/e^+ source	1.5	low β^*, injection
charge switch	?	EC, lower e^+ current

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