STATUS OF KEKB PROJECT

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Abstract

The KEK B-Factory, KEKB, is an asymmetric-energy, two-ring, electron-positron collider for B physics. Eight GeV electrons stored in a high-energy ring (HER) and 3.5 GeV positrons in a low-energy ring (LER) collide at an interaction point (IP), which BELLE detector surrounds. In order to facilitate detection of CP-violation effect at the bottom-quark sector, the machine is designed to reach a luminosity of $10^{34}cm^{-2}s^{-1}$. Even with a high beam-beam tuneshift of 0.05 and a small β_y* of 1 cm at IP, necessary currents in the rings amount to 1.1 A at HER and 2.6 A at LER. KEKB adopts new schemes to reach the goal, such as ±11 mrad finite-angle collision at IP, non-interleaved-sextupole chromaticity correction to have large dynamic apertures, higher-order-mode-free normal conducting cavity called ARES and single-cell, single-mode, superconducting cavities to prevent coupled-bunch instabilities and combat heavy beam-loading, among others. The project started in 1994 as a five-year project; the machine will be commissioned in the autumn of 1998.

1 BASIC FEATURES OF KEKB

KEKB[1] is an asymmetric-energy, two-ring, electron-positron collider housed in the 3 km TRISTAN tunnel. Eight GeV eletrons and 3.5-GeV positrons are stored in different rings; they circulate in opposite directions, and collide at one interaction point (IP). The BELLE detector[2] surrounds the IP. In order to avoid ion-trapping in an electron ring, which becomes stronger at low energy, the higher-energy ring is assigned to store electrons. The electron ring, therefore, is called the high-energy ring (HER), and the positron ring the low-energy ring (LER). The cross section of the tunnel is large enough to enable a side-by-side installation of LER and HER. The two rings change their inner-outer position at the IP and at a crossover point opposite to the IP, where LER and HER have different heights and electrons and positrons do not collide. The interchange of inner and outer position of the rings is necessary to make the two rings have the same circumference.

The injector linac is now being upgraded from 2.5 GeV to 8 GeV in order to facilitate direct injection of electrons and positrons to the rings and to increase the intensity of the positrons by raising the energy of electrons impinging on a positron-production target[3]. Figure 1 shows a schematic layout of KEKB.

The main objective of KEKB is to detect the CP violation effect at the bottom-quark sector. If we move to the center-of-mass frame from the laboratory one, a 5.3-GeV electron and a 5.3-GeV positron collide and produce a pair of B meson and anti-B meson at rest at the Υ(4S) resonance. In the laboratory frame where an 8-GeV electrons and a 3.5-GeV positron collide, the B and anti-B mesons move along the direction of the incoming electron, travel over a few hundred μm, and decay at different positions. By detecting the decay products, we can identify the B and anti-B mesons. This identification is essential for studying CP-violation, which is a subtle difference in behavior between particles and anti-particles.

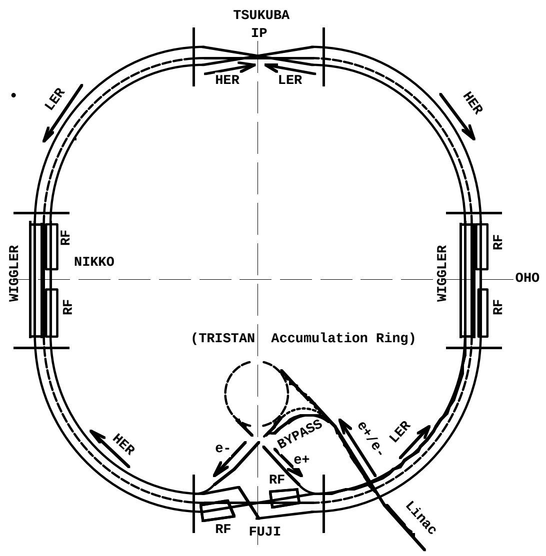

Figure 1 Layout of KEKB

KEKB aims to achieve a luminosity of $10^{34}cm^{-2}s^{-1}$, which is necessary for the CP-violation detection. The luminosity (L) is given by

$$L = 2.2 \times 10^{34} \xi (1 + r) \left(\frac{E \cdot I}{\beta_y^*} \right)_{\pm} \qquad (1),$$

where ξ is the beam-beam tuneshift, r the ratio between the vertical beam size to the horizontal beam size at the IP (usually r<<1 and is negligible), I the current in ampere, E the beam energy in GeV, and β_y* the β-value at the IP in cm. The ± sign means that this formula is applicable to both electrons and positrons. In order to reach a high luminosity, ξ and I should be maximized, and β_y* minimized.

The parameter ξ is a measure of the beam-beam force between colliding bunches, and usually takes a value between 0.03 and 0.05. The parameter β_y* is a measure of beam focusing at the IP. The minimum attainable value of β_y* is determined by a chromaticity produced by final focus quads. If β_y* becomes too small, the beam size in the final-focus quads increases beyond the limit of the chromaticity correction by sextupoles. The allowable minimum value is around 1 cm. At KEKB, we assume ξ is 0.05 and β_y* is 1cm. If we insert L=10^{34}cm^{-2}s^{-1}, ξ=0.05, β_y*=1 cm, and E=3.5 GeV and 8 GeV in the formula (1), we find that we should store 2.6 A in the positron ring and 1.1 A in the electron ring. The main issue of KEKB is, therefore, how to store such large currents in the rings and to achieve stable collisions between the beams under the high beam-beam tuneshift.

These large currents are distributed into 5000 bunches per ring; except for a few % of the whole buckets (bunch gap), every bucket in a ring is filled with the beam. The bunch gap is necessary for ion clearing. At KEKB, single-bunch current is well below the threshold of single-bunch instabilities; only coupled-bunch instabilities are of concern.

Wigglers are used to shorten the damping time of LER down to that of HER. The total synchrotron radiation power amounts to 4 MW per ring; Copper vacuum ducts are used to sustain high heat from the radiation.

It is advantageous to inject beams into the rings with the same optics as those for the collision mode. This requires that the dynamic aperture of the ring be large enough for injection even with the minimum β_y* of 1 cm. A non-interleaved-sextupole chromaticity correction scheme is adopted to have enough dynamic apertures at injection and at collision[4]. Table 1 summarizes the main parameters of KEKB.

2 COUPLED-BUNCH INSTABILITIES AND CAVITIES

Large stored currents excite strong coupled-bunch instabilities due to higher-order modes (HOMs) and a fundamental mode of cavities. A straight-forward way to avoid coupled-bunch instabilities due to HOMs is to use a cavity where no HOMs are excited by the beam. KEKB uses two kinds of HOM-free cavities: normal conducting cavities, called ARES[5,6,7], for LER and HER, and superconducting cavities (SCC) for HER[8,9].

ARES is an acronym of Accelerator Resonantly coupled with Energy Storage. The schematics of ARES is shown in Fig. 2. It consists of three cells: an accelerating

Table 1. Main Parameters of KEKB.

Ring		LER		HER	
Energy	E	3.5		8.0	GeV
Circumference	C		3016.26		m
Luminosity	L		1 x 10^{34}		cm^{-2}s^{-1}
Crossing angle	θ_x		± 11		mrad
Tune shifts	ξ_x/ξ_y		0.039 / 0.052		
Beta function at IP	β^*_x/β^*_y		0.33 / 0.01		m
Beam current	I	2.6		1.1	A
Natural bunch length	σ_z		0.4		cm
Energy spread	σ_d	7.4 x 10^{-4}		6.7 x 10^{-4}	
Bunch spacing	S_b		0.59		m
Particles/bunch		3.3 x 10^{10}		1.4 x 10^{10}	
Emittance	$\varepsilon_x/\varepsilon_y$		1.8 x 10^{-8}/ 3.6 x 10^{-10}		m
Synchrotron tune	ν_s		0.01 ~ 0.02		
Betatron tune	ν_x/ν_y	45.52 / 45.08		46.52 / 46.08	
Momentum compaction factor	α_p		1 x 10^{-4} ~ 2 x 10^{-4}		
Energy loss/turn	U_o	0.81† / 1.5††		3.5	MeV
RF voltage	V_c	5 ~ 10		10 ~ 20	MV
RF frequency	f_{RF}		508.887		MHz
Harmonic number	h		5120		
Longitudinal damping time	τ_E	43† / 23††		23	ms
Total beam power	P_B	2.6† / 4.5††		4.0	MW
Radiation power	P_R	2.1† / 4.0††		3.8	MW
HOM power	P_{HOM}	0.57		0.15	MW
Bending radius	ρ	16.3		104.5	m
Length of bending magnet	l_B	0.915		5.86	m

† without wigglers †† with wigglers

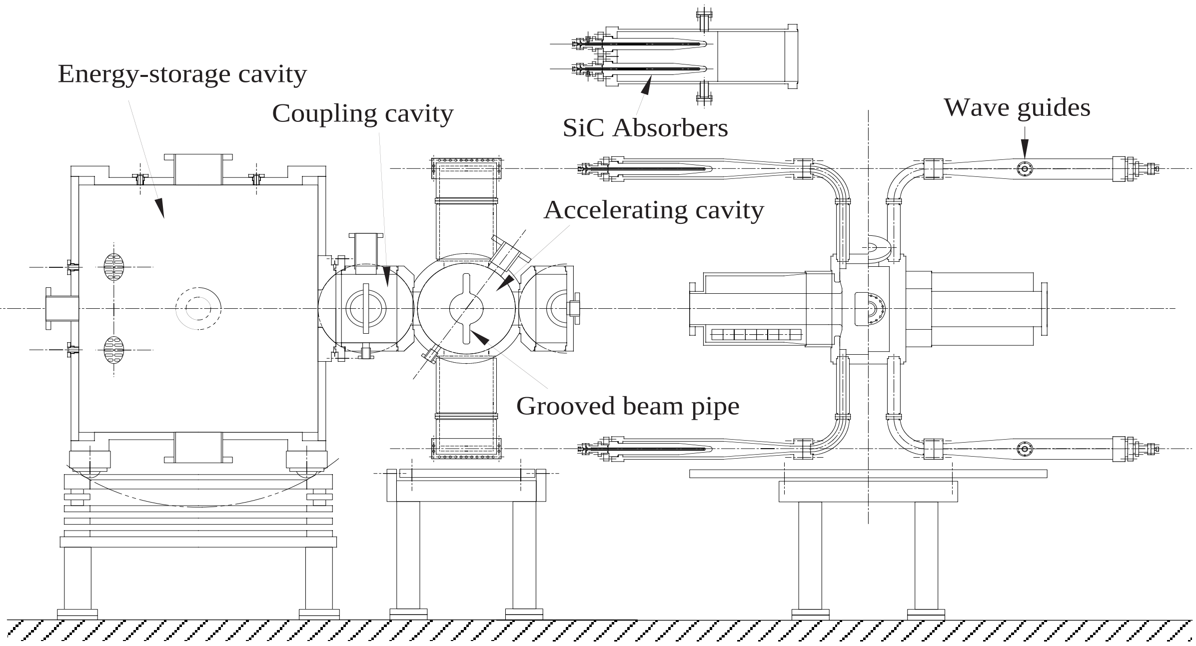

Figure 2 ARES for KEKB

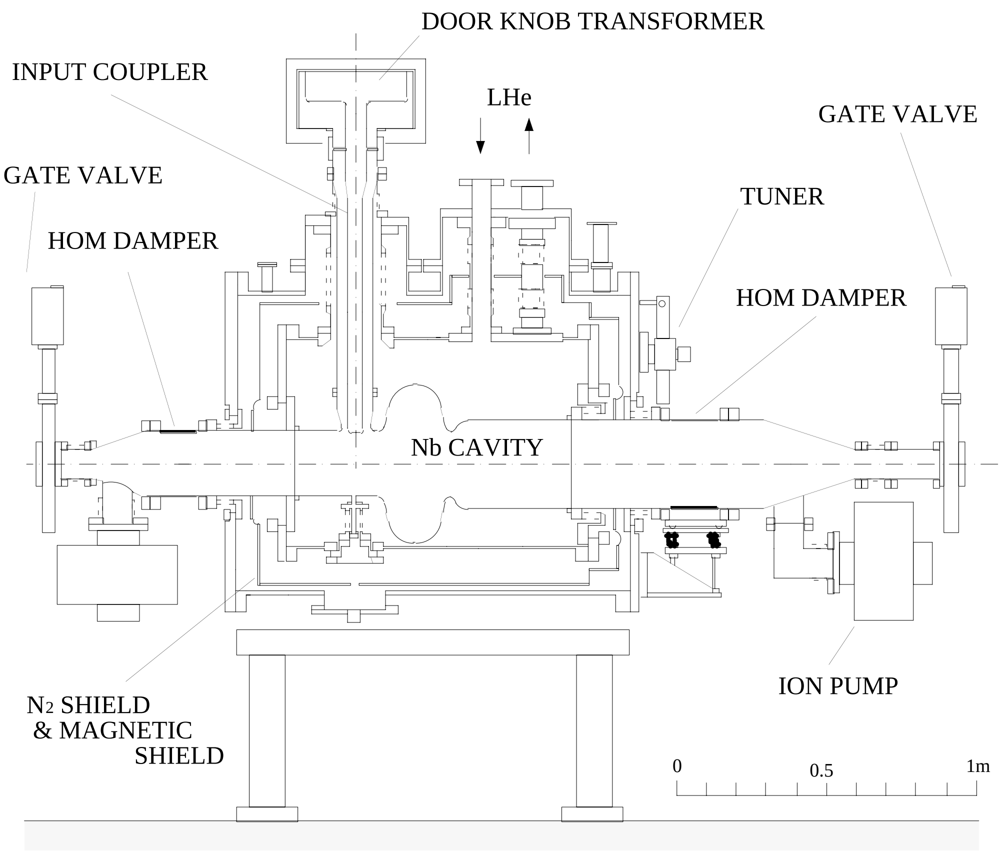

Figure 3 Superconducting cavity for KEKB

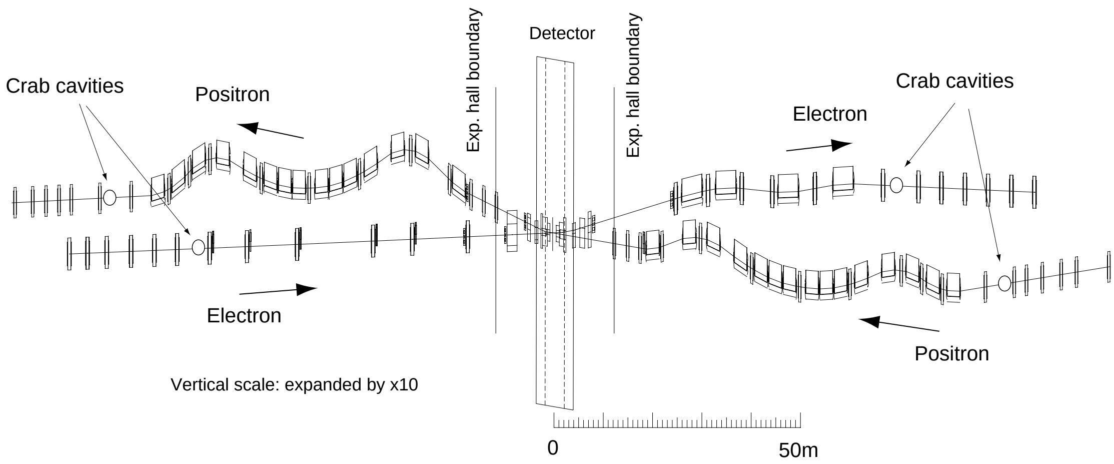

Figure 4 Layout of the KEKB interaction region

cell, an energy-storage cell, and a coupling cell between them. HOMs are extracted from the cavity by four wave guides attached to the accelerating cell, and are absorbed by SiC absorbers equipped at the end of the wave guides. Beam pipes attached to the cell are grooved to make a few HOMs that cannot be extracted by the wave guides propagate towards the beam pipes. The large-volume, low-loss, energy-storage cell effectively increases the stored energy of the cavity system.

Figure 3 depicts the superconducting cavity for KEKB. Two large-bore beam pipes are attached to both ends of the cavity cell. The diameters of the beam pipes are chosen so that the frequencies of all modes, except for the fundamental one, become higher than the cut-off frequencies of the pipes. HOMs propagate towards the beam pipes and eventually become absorbed by ferrite dampers attached to the inner surface of the pipes.

Both ARES cavity and superconducting cavity have large stored energies, which make them strong against heavy beam-loading; no coupled-bunch instability due to the fundamental mode of the cavities is excited.

3 FINITE-ANGLE CROSSING AND CRAB CROSSING

After an electron bunch and a positron bunch collide at the IP, these bunches should be quickly separated in order to avoid parasitic beam collisions at n x $S_b/2$ apart from the IP, where n is an integer and S_b is the bunch spacing (59 cm at KEKB). KEKB adopts a horizontal finite-angle crossing of ±11 mrad to avoid the first parasitic collisions at points 30 cm away from the IP. The finite-angle crossing scheme is advantageous, since it eliminates the use of separation dipole magnets that produce synchrotron lights close to the IP. Figure 4 shows the layout of the KEKB interaction region.

At a finite-angle collision, particles in a bunch receive different transverse kicks from the opposing bunch according to their longitudinal position in the bunch. This dependence makes the longitudinal and transverse oscillation of the bunches couple to each other and excite synchrobetatron resonances. Although extensive simulations done at KEKB show no decrease of luminosity and no increase of beam tails due to the finite-angle crossing, KEKB is considering adopting a crab-crossing scheme as a backup to solve any unforeseeable problems due to the finite-angle crossing.

Figure 5 depicts the crab-crossing scheme[10,11]. Incoming bunches are tilted by half a crossing angle by crab cavities and collide head-on in the center-of-mass frame at the IP. Outgoing bunches are tilted back again by other crab cavities.

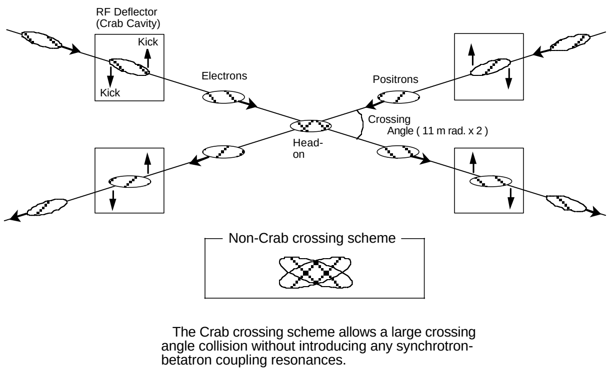

Figure 5 Crab–crossing scheme

The function of a crab cavity is to give a sidewise kick to the bunches. This is accomplished by utilizing the TM110 mode, one of the higher-order modes of the cavity. By precisely adjusting the phase of the cavity with respect to the arrival time of the bunch, we can make the kick that a particle gets from the opposing bunch proportional to the distance between the center of the bunch to this particle, with the center of the bunch receiving no net kick. Quadrupole magnets between the crab cavity and the IP translate these kicks into sidewise position displacement at the IP and the bunch gets tilted.

4 PHOTOELECTRON AND FAST ION INSTABILITIES

Two new transverse coupled-bunch instabilities, the fast-ion instability (FII)[12,13] and the photoelectron instability (PEI)[14], may be serious to KEKB. Simulations predict that the growth time of these instabilities at KEKB is one msec or shorter[15,16]. Since the vertical beam size is small compared to the horizontal beam size, only vertical oscillations are excited by these instabilities.

FII is an ion-related, vertical coupled-bunch instability, and of serious concern for HER. When a bunch train of electrons passes a point in the ring, each bunch creates ions by residual-gas ionization. These ions are accumulated as trailing bunches pass the point. During the bunch gap, the accumulated ions are cleared out. Every time, the first bunch of the train sees fresh gas. This situation is different from that of the usual ion trapping, where ions are permanently trapped by the beam.

If some bunch in the train is displaced vertically, ions created by this bunch are also displaced. These ions and trailing bunches attract each other and start to oscillate. As a result, the oscillation of bunches is resonantly excited by ions. One of the features of the instability is that bunches in the tail of the train have a larger oscillation amplitude. All three experiments concerning this instability, at LBL ALS[17], at KEK AR[18], and at PLS at PAL[19], observed that the oscillation amplitude grew along the bunch train

PEI, is a serious concern for LER. Synchrotron lights emitted by the positron beam hit the inner surface of the vacuum ducts and produce secondary electrons. These electrons are attracted by the positron beam and move towards the beam. Although electrons stay only a few ten nsec in the vacuum duct and are absorbed by the duct wall, continuous production and absorption of electrons result in the formation of an electron cloud around the beam. Transverse motion of a positron bunch in the train changes the distribution of electrons in the cloud; this perturbed electron density in the cloud works as a source of wake, and excites the coupled-bunch instability.

PEI was first observed at the KEK Photon Factory ring[20] and confirmed at BEPC of IHEP by the IHEP-KEK collaboration[21].

The most effective way to combat FII and PEI is to use strong, bunch-by-bunch feedback systems with a damping time faster than 1 msec[22]. For PEI, weak solenoid field of 30 Gauss can confine the electron cloud very close to the vacuum duct and reduce the strength of the wake. A winding machine is now under development.

6 THE SCHEDULE

The construction of KEKB was approved by the Japanese government in 1994 as a five-year project; The year 1998 is the last year of its construction. In May-June, a fully upgraded linac, and from October 1998, HER and LER will be commissioned. The start of physics experiments is to be in early 1999.

At SLAC, another B-Factory called PEP-II is under construction and will be completed also in 1998[23].

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