KEKB STATUS AND PLANS

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ABSTRACT

The Japanese B-Factory project at KEK (KEKB) was approved by the Japanese government in 1994 as a five-year project and the construction of accelerator and detector started in April 1994. KEKB is an 8 × 3.5 GeV, two-ring, electron-positron collider in the existing TRISTAN tunnel. The luminosity goal is 10^{34} cm^{-2}s^{-1}. KEKB has one interaction point where electrons and positrons collide at a finite angle of ± 11 mrad. BELLE detector will be installed around this interaction point. KEKB will be commissioned in JFY 1998.

I. INTRODUCTION

KEKB(B-Factory) is an 8 × 3.5 GeV, two-ring, asymmetric, electron-positron collider aiming at detecting the CP-violation effect at B-mesons. Its luminosity goal is 10^{34} cm^{-2}s^{-1}. The project has been approved by the Japanese government as a five-year project and the construction has started from April 1994. Two rings of the KEKB (3.5 GeV low-energy ring, LER, for positrons, and 8 GeV high-energy ring, HER, for electrons) are to be installed in the existing TRISTAN tunnel of 3 km circumference and the infrastructure of TRISTAN will be maximally utilized. Taking advantage of the large tunnel size of TRISTAN, two rings of KEKB will be installed side by side; unnecessary vertical bending of trajectories that may increase the vertical emittance of the beams is minimized.

Figure 1 illustrates the arrangement of two rings. KEKB has only one interaction point, IP, at Tsukuba experimental hall, where electron and positron beams collide at a finite angle of ± 11 mrad. BELLE detector will be installed at IP. The straight section at Fuji is used for injection from the linac and also for installing RF cavities of LER. RF cavities of HER are to be installed in straight sections at Nikko and Oho. These straight sections are also reserved for wigglers for LER. The wigglers reduce the longitudinal damping time of LER from 43 msec to the same value as that of HER, 23 msec. In order to make the circumference of the two rings equal, a cross-over should be made at Fuji experimental hall where two rings pass each other.

To facilitate full-energy injection into the KEKB rings from linac and avoid acceleration of high-current beams, the present 2.5 GeV electron linac will be upgraded to 8 GeV[1]. The upgrade is done by combining the main linac with the positron production linac, increasing the number of accelerating structures, replacing klystrons with high-power ones, and compressing RF pulses by SLEDs. By this upgrade we can increase the energy of electrons impinging on the positron production target from 250 MeV to 4 GeV, thus multiplying positron intensity by 16. The injection time of positrons to LER is estimated to be 900 sec. A new bypass tunnel of 130 m for transport lines between the linac and KEKB rings will be constructed. This bypass tunnel insulates accumulation ring, AR, from KEKB; this is convenient both for KEKB and AR, since upgrade of either accelerator can be done without any large perturbation to the other. The tunnel will be constructed in JFY 1996 and 1997.

II. BASIC DESIGN

A. Beam Parameters

The main parameters of the KEKB accelerators are given in Table 1. HER and LER have the same circumferences, emittances, and the ß functions at IP. The large current, the large number of bunches, small bunch spacing, the small value of ß function at IP and finite-angle crossing of beams are the salient features of KEKB.

B. Noninterleaved Chromaticity Correction and 2.5π Lattice

It is desirable if we can inject beams into KEKB with the same optics as that of collision and avoid changing optics with large stored currents in the rings. We should have large enough transverse dynamic apertures at injection both for LER and HER, and a large enough longitudinal (momentum) aperture to have a sufficiently long Touschek lifetime for LER. Touschek lifetime is not a concern in HER because of

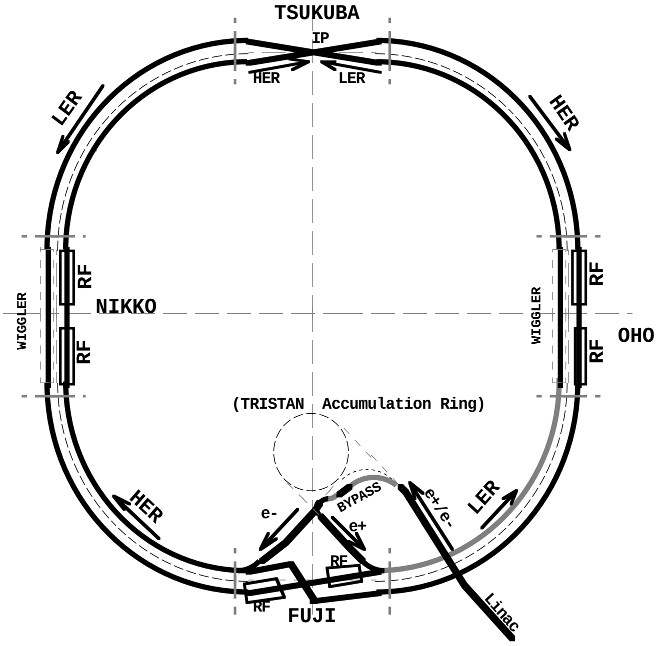

Fig. 1 Configuration of KEKB accelerator system.

its 8 GeV energy. We have decided to adopt a noninterleaved sextupole chromaticity correction scheme to increase the apertures[2]. Between a pair of sextupoles no other sextupoles are installed and the betatron phase advance is π in both horizontal and vertical planes. This scheme cancells out the geometric aberrations of the sextupole by the -I transformation between sextupoles in a pair.

One unit cell of the adopted lattice has a phase advance of 2.5π and includes two pairs of sextupoles, SF and SD, of -I transformation. The addition of extra π/2 phase advance over 2π cell in this scheme enables effective correction of chromatic kicks and significantly improves the dynamic apertures. The momentum compaction factor can be changed from -1×10^{-4} to 4×10^{-4}. By adding two quadrupoles in a cell we can also have a tunability of the emittance from 50% to 200% of the nominal value. This flexibility of changing the momentum compaction factor and the emittance makes a strong tool to tune the machine.

The local chromaticity correction scheme corrects the large vertical chromaticity produced by the final focus quadrupole magnets within a straight section where IP is located. A few dipole magnets in the straight section produce the dispersion required for chromaticity correction by sextupole magnets. One -I sextupole magnet pair, installed in each side of the IP, corrects the vertical chromaticity. This scheme is applied only for LER where the large momentum aperture is required to imcrease the Touschek lifetime. Since the requirement on the dynamic aperture for HER is less demanding, HER does not employ the scheme.

C. Finite-Angle Crossing of Beams

We have decided to adopt a finite-angle crossing scheme of ± 11 mrad. In this scheme, parasitic collision is not a concern even though every bucket is filled with beam and we can remove separation dipole magnets that would be necessary for a head-on collision. In the case of a head-on collision, synchrotron lights produced by the separation dipole magnets determine the horizontal width of the beam pipe at IP; this width is minimized in the finite-angle crossing where no separation dipole exists; smaller beam pipe improves the vertex point resolution and permits efficient use of the

Table 1 Main Parameters of KEKB

Ring		LER		HER	
Energy	E	3.5		8.0	GeV
Circumference	C		3016.26		m
Luminosity	L		1×10^{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_δ	7.1×10^{-4}		6.7×10^{-4}	
Bunch spacing	s_B		0.59		m
Particles/bunch		3.3×10^{10}		1.4×10^{10}	
Emittance	$\varepsilon_x/\varepsilon_y$		$1.8 \times 10^{-8}/3.6 \times 10^{-10}$		m
Synchrotron tune	ν_s		0.01 ~ 0.02		
Betatron tune	ν_x/ν_y	45.52/45.08		47.52/43.08	
Momentum compaction factor	α_p		$1 \times 10^{-4} \sim 2 \times 10^{-4}$		
Energy loss/turn	U_o	$0.81^{\dagger}/1.5^{\dagger\dagger}$		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	$43^{\dagger}/23^{\dagger\dagger}$		23	ms
Total beam power	P_B	$2.7^{\dagger}/4.5^{\dagger\dagger}$		4.0	MW
Radiation power	P_R	$2.1^{\dagger}/4.0^{\dagger\dagger}$		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

luminosity.

In KEKB we use superconducting final-focus quadrupole magnets in order to have a flexibility of tuning. Since we do not need separation dipole magnets, we can install superconducting solenoid magnets at the place where the separation dipole magnets are to be placed for a head-on collision. One superconducting solenoid and one final-focus quadrupole are contained in the same cryostat. By producing a proper reverse solenoid field, we can make the integrated solenoidal field nearly zero between the pair of the first quadrupole magnets. This cancellation is desirable for asymmetric colliders, where complete cancellation of the solenoidal field is necessary in order not to make the beams rotate by different angles between LER and HER.

By computer simulation we found that the finite-angle crossing reduces usable areas in the ν_x-ν_y plane due to synchro-betatron resonances, and that if we make the ν_s(synchrotron tune) smaller than 0.02, a fair amount of areas in the ν_x-ν_y plane is still free from reduction of luminosity due to resonances.[3] We have also started an R&D work on superconducting crab cavities in order to prepare for unpredictable beam-beam effects due to this finite-angle crossing.

D. Impedance Budget and Single-Beam Instability

Impedance budget of the KEKB was calculated[4] by using ABCI, a newly developed 3D program, MASK30, and analytical formulae. The total inductive impedance and loss factor in LER amount to 0.014 Ω and 42.2 V/pC that corresponds to the HOM power of 570 kW. The total loss factor in HER becomes 60 V/pC. This value is larger than that of LER by 18 V/pC due to the large number of cavities. The total HOM power amounts to 150 kW.

We have found that neither bunch lengthening nor the transverse mode-coupling instability will impose a significant limitation on stored bunch current. The threshold bunch current for the microwave instability was found to be twice as large as the design current. At the design intensity, the bunch lengthens only by 20%[5].

The growth time of the transverse coupled-bunch instability due to resistive wall of vacuum ducts in LER is still as short as 5 msec even though we employ a large duct diameter of 94 mm[5]. This instability must be cured by the fast feedback system.

III. HARDWARE SYSTEM

A. RF System

The RF cavity for the KEKB should have a structure by which higher-order modes (HOMs) in the cavity are damped to the level where the growth times of the coupled-bunch instabilities excited by HOMs become comparable to the damping time. The cavity should have enough stored energy in order to make the dutuning frequency of the cavity due to beam loading small compared with the revolution frequency of the ring. We are now developing two types of cavities for the KEKB. One is a normalconducting cavity called ARES and the other is a superconducting, single-cell, single-mode cavity.

B. ARES

ARES (accelerator resonantly coupled with energy storage) was devised in KEK and extensive R&D works are under way[6,7,8,9,10,11]. If the amount of cavity detuning becomes comparable or larger than the revolution frequency of the ring, strong coupled-bunch instability is excited by the fundamental-mode impedance of the cavity. T. Shintake showed that the amount of the detuning frequency can be drastically decreased by attaching a large volume, low-loss, energy-storage cell to an accelerator cell[12]. On the basis of this proposal, K. Akai, T. Kageyama and Y. Yamazaki proposed a 3-cell structure, where an accelerating cell and an energy storage cell is connected to a coupling cell[13,14]. The system employs a $\pi/2$ mode where almost pure TM010 mode and almost pure TE013 mode are excited in the accelerating cell and the energy storage cell, respectively, and very little field is excited in the coupling cell. Two parasitic modes (0 and π modes) have a field in the coupling cell and can be damped rather easily by a coupler attached to the cell.

In order to suppress HOMs, a choke-mode cavity [15] is used as the accelerating cell of ARES. The choke reflects back the fundamental mode; HOMs propagate out and are absorbed by the SiC absorbers. The first prototype choke-mode cavity was delivered to KEK. It was successfully tested up to 110 kW of wall dissipation which corresponds to a gap voltage of 0.73 MV.

C. Superconducting RF Cavity

A superconducting cavity has a large stored energy due to its high field gradient and is immune to the beam-loading. The superconducting cavity for KEKB is a single-cell cavity with two large-aperture beam pipes attached to the cell[16]. HOMs propagate toward the beam pipes, since their frequencies are above the cut-off frequencies of the pipes. The diameter of the one pipe (300 mm) is made larger than that of the other (220 mm) in order to make a few transverse modes otherwise trapped propagate. The iris between the cell and the larger beam pipe prevents the fundamental mode from propagating toward the beam pipe. HOMs are absorbed by ferrite HOM absorbers.

A full-size Nb model was constructed and tested in a vertical cryostat. The maximum accelerating field obtained was 14.4 MV/m with a Q value of 10^9[17]. The prototype cavity for the AR beam study is under construction and will be teste in AR with beams.

Prototype HOM dampers were made by HIP(hot isostatic press) method: the powder of ferrite is sintered and bonded simultaneously on the Cu surface under high temperature and high pressure. Two HOM dampers, one with an inner diameter of 300 mm and the other with an inner diamter of 220 mm, were high-power tested with 508 MHz RF power upto 14.8 kW and 11.7 kW, respectively. No damage on the ferrite was observed and the outgassing rate was sufficinetly low. A beam test of dampers is in preparation[18].

D. Bunch-by-Bunch Feedback System

Feedback systems that can damp the coupled-bunch oscillations of the beam with a bunch spacing of 2 ns are being developed[19]. Since the number of bunch is large (5000) and the bunch spacing is short (2 ns) at KEKB, the signal processing part of the system needs a lot of R&D. We are trying to develop a 2-tap FIR digital filter system as the kernel of the signal processing unit. The 2-tap FIR filter does not require any multiplication but a substraction of two signals. This kind of filter can be composed of memory chips and simple CMOS logic ICs without relying on DSP chips. By using 500 MHz ADC and DAC, two custom-made 4-bit GaAs 1:16 500-MHz demultiplexers and two 4-bit GaAs 16:1 500-MHz multiplexers, and having 16 parallel 2-tap FIR logics, we can construct a signal processing unit on a single board. This board have a capability of processing 5000 beam bunches with 2-nsec spacing without resort to down-sampling technique. This processing speed makes it applicable also to the transverse feedback system. Prototype transverse and longitudinal pickups that can detect bunch oscillations for the 500 MHz bunch frequency have been completed. Kickers are now being developed.

E. Cu Vacuum System

We have decided to use Cu as material for vacuum ducts by taking into account its low photodesorption coefficient, high thermal conductivity, and self shielding capability of X-rays. In LER the maximum heat load due to synchrotron lights to the duct amounts to 15.3 kW/m and that in HER 12.5 kW/m. The use of aluminum as a material is precluded by these numbers.

The cross section of a LER duct is a circle with an inner diameter of 94 mm. These large duct size and short dipole magnets of LER enable us to have a non-distributed pumping system for LER. NEG cartridges will be used as main pumps. Since the instability due to resistive wall is not strong at HER, a race-tarck shape duct is adopted for HER in order to minimize the gap of the dipole magnets. Long dipole magnets of HER only permit us to adopt a distributed pumping system on the basis of NEG strips.

F. Control System

We have decided that we will build the KEKB control system from the EPICS tool box[20].

IV. SCHEDULE

A. Beam Test of RF Cavities and Feedback Systems at the TRISTAN AR

Three-month long beam test is planned to be held in 1996 by the use of AR. We plan to store more than 500 mA electron beam in AR with a multibunch mode at 2.5 GeV. To accumulate this high current, the existing APS type RF cavities will be removed temporally from the ring and an ARES cavity and a single-cell superconducting cavity for KEKB will be installed. The transverse and longitudinal feedback systems will be also installed and tested.

B. Construction Schedule

Main components of LER such as magnets and vacuum equipment will be procured in JFY1995 and 1996, whereas those for HER in JFY1996 and 1997. TRISTAN will be terminated by the end of 1995 and dismantling of TRISTAN main ring will start from January 1996. By the end of 1996 the TRISTAN tunnel will become ready for installation of magnets. We plan that commissioning will start within JFY 1998.

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