Accelerator Design of the KEK B-Factory

Shin-ichi Kurokawa, Kotaro Satoh, Fumihiko Takasaki
and B-Factory Accelerator Task Force

KEK, National Laboratory for High Energy Physics
Oho, Tsukuba, Ibaraki, 305, Japan

Abstract

A design study has been made for the KEK B-Factory, an accelerator complex dedicated to the detection of the CP-violation effect of B-mesons. It is an asymmetric two-ring electron-positron collider of 3.5 × 8 GeV within a new tunnel measuring 1273 m circumference. The design peak luminosity is to be 10^{34} cm^{-2}s^{-1}, which will be realized in two steps. The luminosity is to be 2×10^{33} cm^{-2}s^{-1} with a head-on collision scheme in the first step; it is then increased to a final value of 10^{34} cm^{-2}s^{-1} with a finite-angle crossing scheme.

I. INTRODUCTION

Based upon the assumption that horizontal and vertical beam-beam tune shift parameters of both beams are equal to a common specified value, ξ, and that both beams have the same cross section at the interaction point (IP), the luminosity is given by the following expression in units of cm^{-2}s^{-1}:

$$L = 2.17 \times 10^{34}\, \xi (1 + r) \left(\frac{I \cdot E}{\beta^*_y}\right)_{+,-} ,$$

where r is the aspect ratio of the beam shape (1 for a round and 0 for a flat beam), I the circulating current in A, E the energy in GeV and β^*_y the vertical beta function at IP in cm. The subscript, + or –, means that it may be taken from either ring. We also assume that beta functions and emittances of the two beams are equal. This condition leads to a complete overlap of both beams during collisions.

We first try to increase the ratio ξ/β^*_y in order to achieve the luminosity with the least current. We assume that ξ is 0.05, which is close to the maximum value achieved in existing machines[1], and that β^*_y is 1 cm. The bunch length should be less than one half of β^*_y in order to maintain the high tune shift limit. We choose a flat beam rather than a round one, since by using the former type it is simpler to construct a final focus system and more suitable to make a beam separation system. Even with these parameters, we require 2.6 A for the 3.5-GeV ring (LER) and 1.1 A for the 8-GeV ring (HER) to obtain the 10^{34} cm^{-2}s^{-1} luminosity. We store positrons in LER and electrons in HER to avoid ion trapping, which is more severe at low energies and at high beam currents.

In order to obtain a short bunch length consistent with the small β^*_y, we require a large RF voltage, which needs a large number of RF cavities. On the other hand, the number of the cavities should be kept minimum to avoid any severe beam instabilities. Since V_c $S_B^{2/3}/\sigma^2_z$, where S_B is the bunch spacing and σ_z the bunch length, the RF voltage necessary for a given bunch length can be reduced by decreasing the bunch spacing.

We plan to achieve the final luminosity goals in two steps. First we will build an asymmetric 3.5 × 8 GeV two-ring collide using a head-on collision scheme (step 1). For the head-on collision scheme, we cannot fill every bucket, since we need a length for the separation of electrons and positrons to avoid spurious collisions. Therefore, in the first step, we fill every fifth bucket; this reduces the luminosity to 2×10^{33} cm^{-2}s^{-1}. The reason why we start with a head-on collision scheme is that it is well understood from accumulated experience with many machines. We can accumulate an integrated luminosity of 10^{40} cm^{-2} per year, which is the minimum requirement for detecting the CP-violation effect. We will then modify the interaction region (IR) in order to cope with a finite-angle crossing scheme, possibly crab crossing[2], to reach the final goal of 10^{34} cm^{-2}s^{-1} luminosity; the finite-angle crossing scheme allows us to fill every bucket with the beam. The beam parameters for both steps are essentially unchanged, except for the bunch spacing and the total current. The same lattice is used for both steps with only minor changes of IR. As shown in Fig. 1, the two rings have a race-track shape. There are two long straight sections: one is used for IR and the other is for installing RF cavities and injection systems. At the midpoint of each arc,

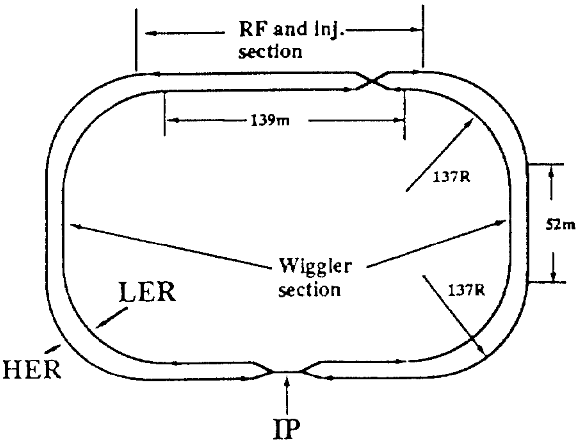

Fig. 1 Configuration of the B-Factory rings.

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VI. RF SYSTEM AND COUPLED-BUNCH INSTABILITY

Large currents, many bunches and short distance between bunches cause strong coupled-bunch instabilities both in the transverse and longitudinal directions. Since the main sources of these instabilities are HOM of accelerating cavities, we are studying a damped cavity, which was first proposed by R.B. Palmer[5] for linear colliders. The basic idea of the damped cavity is that the HOM field is guided to waveguides through slots on the disks of a disk-loaded type cavity. The extracted power of the HOM field is absorbed by a dummy load at the end of the waveguide. The cutoff frequency of the waveguide is set higher than the fundamental accelerating mode frequency.

Figure 3 shows a schematic drawing of the two-cell damped cavity that is presently being investigated at KEK. In Table 2 the HOMs of the damped cavity calculated with the code MAFIA[6] are shown. Each two-cell cavity is fed with RF power through one input coupler.

Imposing constraints that the wall loss per cell be less than 30 kW and that the power through an input coupler be less than 200 kW, the parameters of the RF system have been determined. We require 88 cells for HER and 40 cells for LER.

Table 2 External Q values and R/Q of HOMs calculated with MAFIA

Mode-id	frequency	Qext	R/Q	
TM110-0	989 MHz	<10.0	322	Ω/m
TM110-π	827 MHz	29.9	281	Ω/m
TM111-0	1130 MHz	20.1	1191	Ω/m
TM111-π	1088 MHz	12.0	1862	Ω/m
TM112-0	1200 MHz	223	63.6	Ω/m
TM011-0	952 MHz	*uncoupled*	9.1	Ω
TM011-π	894 MHz	10.6	25.5	Ω
TM012-0	1191 MHz	38.2	8.0	Z
TM012-π	1016 MHz	<10.0	6.6	Ω

We estimated the growth time of coupled-bunch instabilities using the impedances of the modes listed in Table 2. We find that in the first step the expected growth times are longer than the radiation damping times. We plan to use damper systems to be used as a safety factor; in the longitudinal direction, we will make bunch-to-bunch synchrotron-tune spread by installing side-band cavities and in the transverse directions we will use an active damper system.

VII. VACUUM SYSTEM

As design goal of the vacuum system we set a pressure of 10^{-7} Pa at full current of the second step.

We adopt aluminum for the beam pipe in a normal cell, where the heat of synchrotron radiation is less than 10 kW/m. For the wiggler section we should adopt copper beam pipes, since they can be used under a high heat load. We need to develop a fabrication technique of copper beam pipes with a complicated cross section.

The average pumping speed is designed to be 100 *l*/s/m.

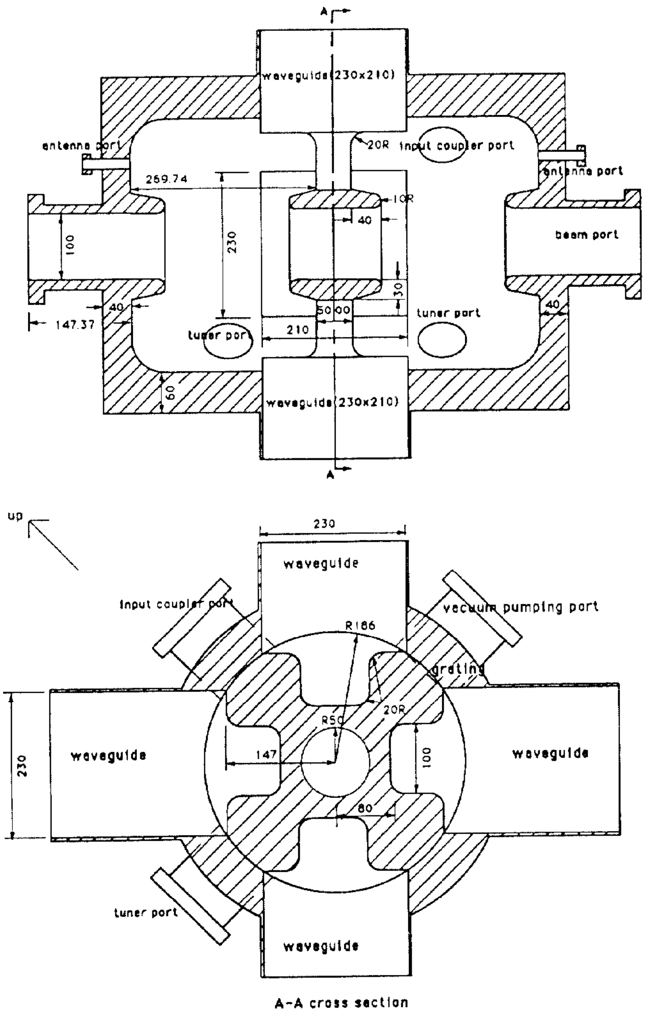

Fig. 3 Schematic drawings of the damped cavity.

VIII. CONCLUSIONS

On the basis of the design presented in this report, we believe, we can construct the KEK B-Factory collider which will satisfy the physics demands.[7][8]

We have started the design of another option for the KEK B-Factory: installing two rings of the B-Factory into the TRISTAN tunnel, whose circumference is 3 km. The design will be finished within 10 months.

IX. REFERENCES

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there is short straight section for wigglers, which control the damping time and the emittances.

II. LATTICE DESIGN

The main parameters of the B-Factory accelerators are given in Table 1 for 10^{34} cm^{-2}s^{-1} and 2×10^{33} cm^{-2}s^{-1}.

In order correct a very large chromaticity arising from the final focus quadrupoles, we are adopting a non-interlaced chromaticity correction method by utilizing 26 pairs of sextupoles. Between a pair of sextupoles no other sextupoles exist and the betatron phase advance is π in both the horizontal and vertical planes. The merit of this scheme is based on the cancellation of the geometric abserations of the sextupoles by a $-I$ transformation in a pair. This scheme, however, may be sensitive to errors involving the optics. Dynamic apertures were estimated by a particle tracking code, SAD[3]. Even if there are Gaussian errors of 0.1 % in the strength of the quadrupoles and 0.2 % in the sextupoles, the dynamic aperture of the ring changes little and satisfies the injection condition, the aperture of 1.2×10^{-5} m at 0.3 % momentum deviation.

Table 1 main parameters of the KEK B-Factory

Energy	E	3.5	8.0	GeV
Circumference	C	1273		m
Luminosity	L	$1\times10^{34}(2\times10^{33})$		cm^{-2}s^{-1}
Tune shifts	ξ_x/ξ_y	0.05/0.05		
Beta function at IP	β^*_x/β^*_y	1.0/0.01		m
Beam current	I	2.6(0.52)	1.1(0.22)	A
Natural bunch length	σ_z	0.5		cm
Energy spread	σ_ε	7.9×10^{-4}	7.2×10^{-4}	
Bunch spacing	S_B	0.6(3.0)		
Particles/bunch	N	3.3×10^{10}	1.4×10^{10}	
Emittance	$\varepsilon_x/\varepsilon_y$	$1.9\times10^{-8}/1.9\times10^{-10}$		
Synchrotron tune	ν_s	0.047	0.051	
Betatron tune	n_x/n_y	27/25	26/25	
Momemtum compaction	α	1.5×10^{-3}	1.8×10^{-3}	
Energy loss/turn	U_0	0.95	4.2	MeV
RF voltage	V_c	15	35	MV
RF frequency	f_{RF}	508		MHz
Harmonic number	h	2160		
Energy damping decrement	T_0/τ_E	2.6×10^{-4}	5.1×10^{-4}	
Bending radius	ρ	14.4	90.9	m
Length of bending magnet	l_B	0.27	3.4	m
Bending magnets/cell		4	2	

Values in parentheses are those for 2×10^{33} cm^{-2}s^{-1}.

III. SINGLE BUNCH INSTABILITY

We evaluated bunch lengthening threshold by using a program developed by K. Oide and K. Yokoya[4]. For LER, where bunch lengthening is more severe than in HER, the threshold is five times as large as the single bunch current necessary for the present design.

IV. INSERTION DESIGN

The insertion layout around IP for head-on collision is shown in Fig. 2. In order to decrease the synchrotron radiation from the incoming beam and to make the two orbits separate quickly, the optics are no longer symmetric with respect to IP.

Beam separation is achieved by permanent bending magnets. On both sides of IP the orbit of the incoming beam goes through the center of the defocusing superconducting quadrupole, QCD. A defocusing QC3H is a half-quadrupole magnet which can be inserted sufficiently close to IP. This magnet focuses the beam vertically and deflects the HER beam outwards, thus helping orbit separation. The outgoing beam orbit is deflected further away from the other by the septum magnets, SEPH and SEPL.

The size of the IP beam pipe is 60 mm wide, 35 mm outside and 25 mm inside, and 30 mm in full height.

Since the detector has a solenoid field of 1 T, (4 m long in total), no ferromagnetic material is allowed within the solenoid, unless the field is eliminated. We plan to insert superconducting compensation coils to cancel out all of the solenoid field, except within 1.1 m from IP. The compensation coil is to be contained within the same cryostat of QCD.

In the present design a simulation shows that the number of photons which hit the IP beam pipe is 10^{-3} per beam crossing. This number is sufficiently small for the detector. We have estimated the rate of spent electrons which enter the detector through the IP beam pipe. If we assume a 10^{-7} Pa vacuum around IR, the rate becomes 0.8 kHz for 8 GeV at 0.26 A and 8 kHz for 3.5 GeV at 0.55 A; these rates are within a manageable range for the detector.

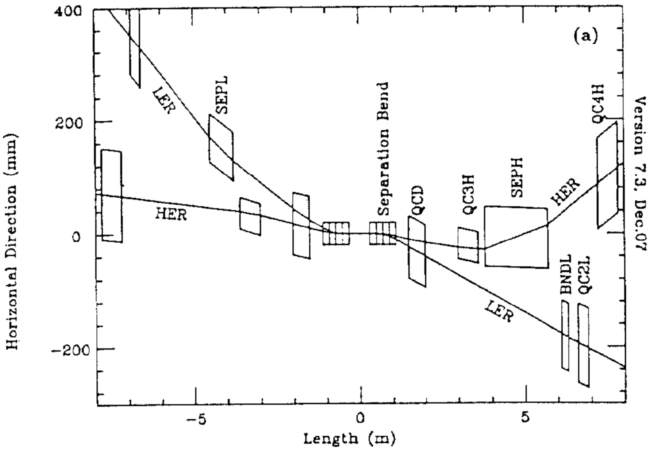

Fig. 2 IR insertion.

V. HEATING OF THE IP BEAM PIPE

We estimated the power dissipation at the IP beam pipe for the first step . The heating of the IP beam pipe caused by the HOMs generated at masks in IR (between 7 to 63 W) and by Ohmic loss (1.4 W) can be managed in the first step, even if we assume a cavity-like structure. If the additional power dissipation caused by the HOMs generated around the ring (200 W) is undersirable, some absorbers will be needed to prevent them from propagating toward IR.