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Accelerator Design of the KEK B-Factory

B-Factory Accelerator Task Force

edited by

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Accelerator Design of the KEK B-Factory

B-Factory Accelerator Task Force

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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 $10^{34} \text{cm}^{-2} \text{s}^{-1}$, which will be realized in two steps. The luminosity is to be $2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$ with a head-on collision scheme in the first step; it is then increased to a final value of $10^{34} \text{cm}^{-2} \text{s}^{-1}$ with a finite-angle crossing scheme.

This document comprises two parts: the first part presents an overview of the design; the second part is a collection of papers giving detailed descriptions of various subjects. Stress is put on the design of the first step; the second step is mentioned when necessary.

Foreword

This report is a summary of work carried out by the KEK B-Factory Accelerator Task Force between April 1990 and January 1991 and covers the design of accelerators for the KEK B-Factory. The members of the Task Force are listed below. Physics issues are covered by another report entitled 'Physics and Detector of Asymmetric B-Factory at KEK' (KEK Report 90-23).

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PART I

General Description of the Accelerator Design

1. Introduction

An asymmetric two-ring electron-positron collider for B-physics, the KEK B-Factory, is now being planned as one of the future projects at KEK[1]. The basic requirements on the B-Factory, such as the beam energies and luminosity, have been set on the basis of the following physics demands[2]:

1. Measurement of the CP-violation parameters at $\Upsilon(4S)$; this requires a 3.5×8 GeV collider with a peak luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$.
2. Measurement of $B_s - \bar{B}_s$ mixing at $\Upsilon(5S)$; this needs a 2.5×12 GeV collider with a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$.

In designing the B-Factory collider, we have followed the guidelines listed below:

1. Construct a new tunnel housing two rings of the same circumference, about 1300 m.
2. Envision only one interaction region in order to concentrate effort on achieving a maximum luminosity for the detector.
3. The present TRISTAN injector system (a 2.5 GeV electron linac and an 8 GeV accumulation ring) [3] be used at least for the first operation of the B-Factory.

We plan to achieve the above-mentioned goals in two steps. First we will build an asymmetric 3.5×8 GeV two-ring collider using a head-on collision scheme with a luminosity of $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$ (step 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 to reach the final goal of $10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosity; the finite-angle crossing scheme allows us to fill every bucket with the beam. Since maintaining such a high luminosity requires effective injection, we will add a rapid-cycle booster synchrotron in the same tunnel. 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 Figs. 1 and 2, 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, there is a short straight section for wigglers.

The rings were designed so that they can also be operated for 2.5×12 GeV collisions, where the booster synchrotron is used to inject a 12-GeV beam. A detailed design should be made.

Figure 1: Layout of the B-Factory at the KEK site.

Figure 2: Configuration of the B-Factory rings.

2. Design Principle

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 $\text{cm}^{-2}\text{s}^{-1}$:

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

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[5], 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 and 1.1 A for the 8-GeV ring to obtain the $10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosity. We store positrons in the low-energy ring (LER) and electrons in the high-energy ring (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. What is the minimum RF voltage required to obtain a given bunch length? We show a possible solution below, guided by the paper #1 in this report.

If the total current I is given, the number of particles per bunch N is expressed as

$$N = \frac{IS_B}{ec}, \quad (2)$$

where S_B is the bunch spacing, e the charge of an electron and c the speed of light. Remembering the definition of the beam-beam tune shift parameter,

$$\xi_x^\pm = \xi = \frac{r_e N^\mp}{2\pi\gamma^\pm \varepsilon_x (1 + r)}, \quad (3)$$

we find that the horizontal emittance, ε_x , is given by

$$\varepsilon_x^\pm = \varepsilon_x = \frac{r_e N^\mp}{2\pi\gamma^\pm \xi (1 + r)} = \frac{r_e I^\mp S_B}{2\pi\gamma^\pm c \xi (1 + r)}, \quad (4)$$

where r_e is the classical electron radius and γ the relativistic factor. The necessary RF voltage V_c is, on the other hand, given by the formula,

$$V_c = \frac{2\pi c E}{e\omega_{RF}\sigma_z^2} \left[\left(\frac{55}{64\sqrt{3}} \lambda_e \right)^{1/2} \frac{\gamma \varepsilon_x}{2} \right]^{2/3} \left(\frac{R}{\rho} \right)^{1/3}, \quad (5)$$

where λ_e is the Compton wave length of an electron, ρ the bending radius, ω_{RF} the angular RF frequency, R the average ring radius in the arc, and σ_z the bunch length. If we employ the expression (4) for ε_x , we obtain

$$V_c \propto \frac{S_B^{\frac{2}{3}}}{\sigma_z^2}. \quad (6)$$

Thus the RF voltage necessary for a given bunch length can be reduced by decreasing the bunch spacing.

For a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$ we seek the extreme where every bucket is filled with the beam. We plan to adopt the 508 MHz RF system, since it would be possible to utilize some of the RF equipment which is presently used in TRISTAN. Since the bunch spacing of 60 cm in the second step is too short for any separation device to be installed, we adopt a collision scheme with a finite crossing angle. There may be two types of finite-angle crossing schemes: one is with ~ 50 mrad crossing angle and the other with a few mrad crossing angle. The former needs crab cavities to avoid any geometrical loss of the luminosity and beam blow-up due to the synchrotron-betatron resonance[4]. Superconducting crab cavities are under investigation at KEK. In the latter case, we must use separation bending magnets near IP to separate the beams quickly enough. Here we need not use crab cavities owing to this small crossing angle.

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 $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$.

3. Lattice Design

Optics

The main features of the beam parameters are a very flat beam, small beta functions and low emittances. The main parameters of the B-Factory accelerators are given in Table 1 for $10^{34}\text{cm}^{-2}\text{s}^{-1}$ and $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$. Figures 3 and 4 show the linear optics of the rings. HER and LER have the same circumference, emittance and β^* s. This leads to similar betatron tunes and energy spreads in both rings. The radiation damping time of LER becomes twice as long as that of HER, if only radiation in the arcs is taken into account. We prepare wiggler sections in both rings in order to control the damping time and the emittances over a wide range

of flexibilities. We can add wiggler magnets with a total length of ~ 60 m in these sections.

Table 1: Main parameters of the KEK B-Factory.

Energy	E	3.5	8.0	GeV
Circumference	C	1273		m
Luminosity	$\mathcal{L}$	1×10^{34} (2×10^{33})		$\text{cm}^{-2}\text{s}^{-1}$
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)		m
Particles/bunch	N	3.3×10^{10}	1.4×10^{10}	
Emittance	ϵ_x/ϵ_y	$1.9 \times 10^{-8}/1.9 \times 10^{-10}$		m
Synchrotron tune	ν_s	0.047	0.051	
Betatron tune	ν_x/ν_y	27/25	26/25	
Momentum 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 in $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$.

Chromaticity Correction

In order to 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 aberrations of the sextupoles by a $-I$ transformation in a pair. This scheme, however, may be sensitive to errors involving the optics. If there are strength errors of the quadrupoles in the arc, they break down the $-I$ transformation and decrease the dynamic aperture. The strength error of the sextupoles makes the cancellation incomplete.

Figure 3: Linear optics of HER.

Figure 4: Linear optics of LER.

Dynamic apertures were estimated by a particle tracking code, SAD[6]. Figure 5 shows changes of the dynamic aperture with the strength errors of the quadrupoles and sextupoles. 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.

Figure 5: Change of the dynamic aperture with the strength errors of quadrupoles and sextupoles.

Compensation of the Solenoid Field effect around IP

A unique problem involving a two-ring collider is that the design orbits traverse the solenoid field at a finite angle with respect to the central axis of the solenoid both in the finite-angle crossing and head-on collision (due to the separation bend in the solenoid); we must, therefore, cancel the dispersions and the x - y coupling generated by the solenoid field. This cancellation is achieved by adding at least four skew quadrupoles and several bending magnets on either side of IP. Using the compensating coils (see Sec. 6) we could cancel out the solenoid field at the region where the final quadrupoles exist, but there still remains a high (1 T), long (2.2 m) solenoid field around IP. Since we cannot use a perturbative method to determine the strength of skew quadrupoles, we have added to SAD a new facility which deals with the cancellation of the coupling and simultaneous matching of the linear optics.

4. Beam-Beam Effects

The main issue concerning the beam-beam effects for the KEK B-Factory is whether it is possible to achieve a beam-beam tune-shift limit as large as 0.05 for the case where the bunch length is only one half of β_y^* . If $\sigma_z/2\beta_y^*$ is large (≥ 0.1), the experimental results drawn from various machines indicate that the disruption parameter defined by

$$D_y = 4\pi\xi\sigma_z/\beta_y^* \quad (7)$$

has a limit, which ranges between 0.25~0.3[7]. In our design of $\xi = 0.05$ this value becomes 0.31, which is close to the maximum value ever attained.

In order to attain maximum energy transparency, the parameters of the two rings, such as the circumference, emittance, β^* s, bunch length, are made the same. The damping times can be made equal in the two rings by the use of wigglers. The small difference in synchrotron tunes does not affect the beam.

A simulation shows that for the first step, where every fifth bucket is filled with the beam, the separation system (see Sec.6) makes the two beam orbits separate so quickly that the long-range beam-beam force does not affect the beam stability.

5. Single Bunch Instability

RF cavities, bellows with an inner shield and masks in IR are the possible impedance sources which can cause the bunch lengthening. We estimated these impedances and evaluated bunch lengthening threshold by using a program developed by K. Oide and K. Yokoya[8]. The program analyzes the stability of the bunch with the Vlasov equation, including potential well distortion. We only calculated for LER, since bunch lengthening is more severe in LER than in HER. Figure 6 shows the calculated bunch lengthening in LER as a function of the number of particles per bunch. The threshold is five times as large as the single bunch current necessary for the present design. We may conclude that bunch lengthening does not take place in the KEK B-Factory.

6. Insertion Design

Constraints imposed on the insertion design is the following:

1. From the view point of physics experiments the beam pipe radius at IP (we call this Be pipe surrounding IP "the IP beam pipe") must be sufficiently small; however, it must be sufficiently large in order that synchrotron light emitted by incoming beams does not hit the pipe and masks near IP.
2. Accelerator components inside the detector must not interfere with the experiment. The components should be confined to within a conical region spreading by 300 mrad from the central axis.

Figure 6: Bunch length as a function of the number of particles per bunch.

3. The beam aperture of insertion must be sufficiently wide in accordance with the acceptance required for injection, which is 1.2×10^{-5} m.

The insertion layout around IP for head-on collision is shown in Fig. 7. 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 method for choosing the deflection angle of the separation bending magnet involves a compromise between the size of the IP beam pipe and the chromaticity produced in the insertion. The deflection angle is determined by the condition that synchrotron radiations from incoming particles on the LER center orbit must be confined within 27 mm from IP in the horizontal direction. The size of the IP beam pipe is 60 mm wide, 35 mm outside and 25 mm inside, and 30 mm in full height (see Fig. 8).

Figure 7: Insertion layout around IP: (a) a whole view and (b) a close view.

Figure 8: Cross section of the IP beam pipe.

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.

7. Background Consideration

Two sources of background to the detector have been identified: one is synchrotron light radiated in both dipole and quadrupole magnets near IR; the other involves electrons and positrons which have lost some part of their energy due to the interaction with residual gas (these electrons and positrons are called "spent electrons"). The IP beam pipe and the masks have been designed according to the following guidelines:

1. Photons radiated from the beam within the dipole and quadrupole magnets should not directly hit the IP beam pipe.
2. Masks should intercept photons scattered by vacuum pipes to prevent them from hitting the IP beam pipe.
3. Masks for spent electrons should be located at some distance from the IP beam pipe to prevent any shower leakage from entering the detector.

Figure 9 shows the masking system and beam pipe at IR. 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.

By the use of DECAY TURTLE[9] 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

Masking System and Beam Pipe

Figure 9: Masking system and beam pipe at IR.

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.

8. Heating of the IP Beam Pipe

The IP beam pipe is heated by a higher-order-mode (HOM) RF power generated at masks in IR, by Ohmic loss of image currents which flow on the inner surface of the pipe and by the HOM propagating from outside IR generated around the ring. The physics experiment requires that the heating be at less than 100 W in order to keep the temperature around the pipe less than 50°C, while permitting stable operation of the vertex detector.

We estimated the power dissipation at the IP beam pipe for the first step as follows:

1. As an approximation of the HOM RF power generated at masks, we examined cylindrically symmetric structures and then corrected the result by taking into account the difference between the cylindrical model and the actual structure. A part of the power lost by beam is absorbed at the IP beam pipe. The amount of power dissipated depends on the shape of IR. If there is no cavity-like structure, most of the energy lost by bunches propagates through beam pipes from IR and the power dissipation at the IP beam pipe is 7 W. If the

IP beam pipe and masks form a cavity, a large amount of energy is stored and 63 W is dissipated at the IP beam pipe.

2. The Ohmic loss is estimated to be 1.4 W by assuming that the IP beam pipe is a cylinder.
3. In estimating the HOM RF power generated around the ring, we used the total impedance measured in the TRISTAN Main Ring and scaled it down to the B-Factory ring according to the ratio of the circumference. If we assume that the power is dissipated uniformly around the ring, the absorbed HOM RF power at the IP beam pipe propagating from outside the IR is estimated to be about 200 W. Actually, a part of them whose frequency is below the cut-off frequency of the IP beam pipe does not propagate to it and should be excluded from this estimation.

We conclude that the heating of the IP beam pipe caused by the HOMs generated at masks in IR and by Ohmic loss can be managed in the first step, even if we assume a cavity-like structure. However, if the additional power dissipation caused by the HOMs generated around the ring is undesirable, some absorbers will be needed to prevent them from propagating toward the IR.

9. Injection Scheme and Average Luminosity

We plan to inject positrons into LER and electrons into HER. During the early stage of the KEK B-Factory, the TRISTAN accumulation ring (AR) will be employed as an injector. After improvements, the linac will inject positrons and electrons at a rate of 100 mA/min into AR, which is about 10 times as high as the present rate of positron injection.

In positron injection we plan to fill LER by 22 AR cycles. Each AR cycle accelerates 20 bunches with a total current of 80 mA. The time required for one cycle of AR is 1.5 minutes, most of which is devoted to acceleration and deceleration. The initial positron injection to LER requires 35 minutes. In electron injection, HER is filled by 11 AR cycles, each of which accelerates 40 bunches with a total current of 70 mA; the electron injection takes 20 minutes. As a result, the total injection time becomes 1 hour. In order to realize this injection scheme, we need to modify AR so that it can be operated in a multibunch mode.

The beam lifetime is mainly determined by the particle losses by electron-positron collision[10] and the Touschek effect. The beam lifetime for HER is 3.1 hours and that for LER is 3.7 hours. The exponential decay time of the luminosity is determined by the beam lifetimes of the two rings and becomes 1.7 hours. This lifetime is the same in both steps.

The average luminosity depends on refilling time, T_f , and the luminosity lifetime τ_L . In refilling, each beam is filled by 10 AR cycles; the total time required

to fill the both rings amounts to 30 minutes. From this T_f of 0.5 hours and τ_L of 1.7 hours, the average luminosity becomes 50% of the peak luminosity and the optimum experiment period becomes 1.1 hours. Since we plan to operate the B-Factory for 10^7 seconds per year for physics experiments, the accumulated luminosity per year amounts to 10^{40}cm^{-2} during the first step, where the peak luminosity is $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$.

10. RF System

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[11] 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 10 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[12] are shown. Each two-cell cavity is fed with RF power through one input coupler. In the present cavity design, the TM011-0 mode does not couple to the waveguides; we must develop some method, such as a cone-type dummy load or a coaxial-type dummy load within the waveguides to couple this mode directly to the dummy loads. A prototype damped cavity is now under construction and will be tested in the summer of 1991.

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

Mode-id	frequency	Q_{ext}	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
TE112-0	1200 MHz	223	63.6 Ω/m
TM011-0	952 MHz	<i>uncoupled</i>	9.1 Ω
TM011- π	894 MHz	10.6	25.5 Ω
TM012-0	1191 MHz	38.2	8.0 Ω
TM012- π	1016 MHz	<10.0	6.6 Ω

Imposing constraints that the wall loss per cell be less than 30 kW and that

Damped cavity
508MHz

Figure 10: Schematic drawing of the damped cavity.

Table 3: Parameters of RF system (the first step).

	HER (8.0GeV)	LER (3.5GeV)
Frequency	508 MHz	
Q-value	27800	
Shunt impedance	18.3 M Ω /m	
Power loss	30 kW/cell	28 kW/cell
Voltage	0.40 MV/cell	0.39 MV/cell
Number of cells	88	40
Number of klystrons	11	5
Total cavity voltage	35.6 MV	15.6 MV
Beam loading	51 kW/cell	60 kW/cell
Coupler power	162 kW/coupler	176 kW/coupler
Total length of the cavity section	44 m	20 m

the power through an input coupler be less than 200 kW, the parameters of the RF system have been determined and are given in Table 3. We require 88 cells for HER and 40 cells for LER.

11. Coupled-Bunch Instabilities

Growth Rates of Instabilities

We estimated the growth time of coupled-bunch instabilities using the impedances of the modes listed in Table 2. Table 4 shows the estimated growth times of coupled-bunch instabilities calculated with ZAP[13]. We find that:

1. in the first step the expected growth times are longer than the radiation damping times, and that
2. in the second step we need damping systems to cure coupled-bunch instabilities.

Cure of Instabilities

Although the growth times of the instabilities are longer than the damping times for the first step, where every fifth bucket is filled with the beam, we plan to use damper systems to be used as a safety factor.

To damp coherent dipole oscillations in the longitudinal direction, we will make bunch-to-bunch synchrotron-tune spread by installing side-band cavities. The effect of the tune spread was studied by tracking bunches. By trial and error, we found that the side-band cavities can damp the instability most effectively if its frequency

Table 4: Expected growth time (in msec) of coupled-bunch instabilities.

mode-ID	HER		LER	
	step 1	step 2	step 1	step 2
<i>Longitudinal modes</i>				
<i>rad. damp. time</i>	8		16	
TM011- π	245	19.2	108	8.48
TM012-0	72.0	12.4	31.8	5.47
TM012- π	1532	163	686	73
<i>Transverse modes</i>				
<i>rad. damp. time</i>	16		32	
TM110-0	2.22×10^7	824	9.07×10^6	336
TM110- π	136.	21.5	55.5	8.76
TM111-0	89.9	7.65	36.7	3.12
TM111- π	127	8.89	51.8	3.63
TE112-0	63.8	12.7	26.1	5.18

is $f_{rf} + 40 \cdot f_0$, where f_{rf} and f_0 are the acceleration frequency and the revolution frequency. In Fig. 11 the dashed line shows the minimum tune spread necessary for damping the instability as a function of the HOM impedance. The figure shows that if we reduce the impedance to 150 k Ω /ring, the synchrotron tune spread of 10^{-3} damps the instability. Making this small tune spread requires only one two-cell cavity.

In the transverse directions we will use an active damper system with two deflectors, each of which has four striplines that are 1.3 m long. If the injection error is 1.2×10^{-5} m and 4 kW is fed to each deflector, we can expect the damping time of 2 msec for LER and 5 msec for HER. Figure 12 shows a schematic diagram of the damper system.

Transient Effect

Bunch behavior after injection should be carefully considered [14], since the oscillation amplitude of bunches may grow beyond the aperture of the ring. We studied the behavior by the use of a tracking program and the results are summarized as follows:

1. In both the transverse and longitudinal directions, if the growth time of the coupled-bunch instability is longer than the damping time, the oscillation amplitude of any bunch does not exceed that at injection.
2. In the longitudinal direction, a larger tune spread becomes necessary than that used for stationary states. The solid line in Fig. 11 shows the necessary tune

Figure 11: Required tune spread as a function of the HOM impedance. The dashed line is for stationary case and the solid line is for transient case.

Figure 12: Schematic diagram of the active damper system for transverse coupled-bunch instabilities.

spread as a function of the HOM impedance. If the impedance is 150 k Ω /ring, the tune spread of 2×10^{-3} is required.

12. Vacuum System

Design Guidelines

As a design goal of the vacuum system we set a pressure of 10^{-7} Pa at full current of the second step. This pressure guarantees a long beam life and a low rate of spent electrons to the detector. Additionally, this low pressure will not cause any ion trapping phenomena in HER. The horizontal half aperture of a beam pipe in the arc is to be 50 mm in order to provide high conductance, which is important for obtaining a uniform pressure distribution.

The amount of synchrotron radiation calculated on the basis of the machine parameters of the KEK B-Factory is summarized in Table 5. The wiggler section is exposed to very intense synchrotron radiation, compared to that experienced by a normal cell.

Table 5: Amount of synchrotron radiation.

	LER	HER	
Energy	3.5	8.0	GeV
Beam Current	2.6	1.1	A
<i>Normal cells</i>			
Bending radius	14.4	90.9	m
Critical energy of SR	6.61	12.5	keV
Total SR power	2.40	4.39	MW
Power density (max.)	5.69	7.68	kW/m
Photon density (average)	8.53×10^{18}	8.25×10^{18}	photons/s/m
<i>Wiggler sections</i>			
Magnet field	1.42	0.67	T
Total SR power	5.0	2.6	MW
Total SR photon	8.6×10^{21}	1.8×10^{21}	photons/s
Power density	30~40	~20	kW/m
Photon density	$5 \sim 7 \times 10^{19}$	1.4×10^{19}	photons/s/m

Chamber Material

We adopt aluminum for the beam pipe in a normal cell, where the heat of synchrotron radiation is less than 10 kW/m. We have established techniques for aluminum vacuum systems during the construction of TRISTAN. For the wiggler section we should adopt copper beam pipes, since they can be used under a high

Figure 13: Decrease of η as a function of the photon dose.

heat load. We need to develop a fabrication technique of copper beam pipes with a complicated cross section.

Pumping System

In a conventional design with ion pumps, the average pumping speed is $100 \ell/s/m$. In order to achieve $1 \times 10^{-7} \text{Pa}$, we must wait until the photo-desorption coefficient, η , reduces to 2.5×10^{-7} molecules/photon. We have estimated the decrease of η from the data of AR (see Fig. 13). An η of 2.5×10^{-7} molecules/photon will be realized after 2800 hours of operation under full current. The decay rate of η is inversely proportional to the circulating current and the outgas rate is proportional to both η and the current. The required pressure, therefore, can be realized within the same operation time, even in the first step. A pumping system with an average pumping speed of $100 \ell/s/m$ is shown in Fig. 14. For the wiggler sections the same pumping speed is sufficient to obtain the required pressure, because the photon dose in these sections is larger than that in a normal cell, and η decreases more quickly.

13. Conclusions and Future Prospects

In this report we have presented a summary of the work carried out by the KEK B-Factory Accelerator Task Force between April 1990 and January 1991. It covers the design of the accelerators for the KEK B-Factory, which is an asymmetric two-

[one normal cell]

[One normal cell]

Figure 14: The pumping system in IER and in LER.

ring electron-positron collider of 3.5×8 GeV housed in a new tunnel of 1273 m circumference aiming at the final luminosity of $10^{34} \text{cm}^{-2} \text{s}^{-1}$. This luminosity will be realized in two steps: in the first step every fifth bucket is filled with the beam for a luminosity of $2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$ with a head-on collision scheme; in the second step every bucket is filled with the beam with a finite-angle crossing scheme.

We designed the lattice of LER and HER which have a sufficient dynamic aperture during injection, even with a realistic margin of strength errors of quadrupoles and sextupoles.

In our design of $\xi = 0.05$, the disruption parameter becomes 0.31, which is close to the maximum value ever attained.

The threshold current of bunch lengthening is 5 times as high as the single bunch current; we conclude that no bunch lengthening will take place.

We have designed an IR which should provide adequate beam separation, and at the same time reduce background to the detector to a manageable level.

We estimated the heating of the beam pipe due to beams; the result shows that the temperature rise is sufficiently low to allow a stable operation of the vertex detector.

The injection scheme at the first step (the use of AR) requires 1 hour for the initial filling and 0.5 hours for refilling. The beam lifetime is 3.1 hours for HER and 3.7 hours for LER. From these values the average luminosity becomes 50% of the peak luminosity. Since we can reasonably assume that we will operate the B-Factory for 10^7 seconds per year for physics experiments, the accumulated luminosity will amount to 10^{40}cm^{-2} per year.

We are investigating a Palmer-type damped cavity. Calculations with MAFIA show that we can reduce the Q-values of HOMs of the cavity to a sufficiently low level, although extensive R&D is required to confirm the design.

We do not require any damper system for the coupled-bunch instabilities in the first step. In order to have a safety factor, however, we plan to use side-band cavities to make synchrotron tune spread among bunches; we also plan to use an active damper system in the transverse directions. Both systems are quite feasible.

We have designed a vacuum system which can manage the heat load of the full design current of the second step and realize 10^{-7} Pa within 2800 hours of operation.

The B-Factory project at KEK is regarded as being the third phase of TRISTAN. After having pursued the energy frontier from 25 to 32 GeV, TRISTAN has started its second phase operation in February 1990. In the second phase stress is being placed on accumulating as large an integrated luminosity as possible at modest energy. It will probably take 3~4 years before we can accumulate the 300pb^{-1} integrated luminosity which is the goal of the phase 2 of TRISTAN.

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.

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Machine Parameters of the 10^{34} KEK B-Factory

K. Oide

In designing a high-luminosity collider like the KEK B-Factory, it is necessary to study the complicated interdependences of the system parameters. Although it is quite difficult to handle all of the knowledge simultaneously, we should determine which parameters can be well established by the basic relations, and which can not. First, an important relation,

$$\mathcal{L} = \frac{1+r}{2cr_e} \left(\frac{\gamma_i \xi_{yi} I_i}{\beta_{yi}^*} \right) \quad i = 1, 2, \quad (1)$$

is obtained from the luminosity,

$$\mathcal{L} = \frac{N_1 N_2 f}{4\pi \sigma_x^* \sigma_y^*}, \quad (2)$$

and the beam-beam tune shift parameter,

$$\xi_{x,yi} = \frac{r_c N_{3-i} \beta_{x,yi}^*}{2\pi \gamma_i \sigma_{x,y}^* (\sigma_x^* + \sigma_y^*)}, \quad i = 1, 2, \quad (3)$$

where N_i , $\beta_{x,yi}^*$, $\sigma_{x,y}^*$, I_i , f and r_e are the number of the particles/bunch, β functions and the beam sizes at the interaction point (IP), the beam current, the collision rate, and the classical electron radius. The suffix, $i = 1, 2$, denotes each beam.

We have assumed that the beam sizes of the two beams are equal, since unequal sizes give unequal non-linear beam-beam effects on both beams, which decrease the maximum tune-shift limit. We also assume below that the β functions and the emittances, $\varepsilon_{x,y}$, of the two beams are equal. The equal β functions provide a complete overlap of both beams during collisions. In (1) we have one free parameter,

$$r \equiv \sigma_y^* / \sigma_x^* = \beta_y^* / \beta_x^* = \varepsilon_y / \varepsilon_x, \quad (4)$$

which splits the course of the design into a round beam ($r=1$) and a flat beam ($r \ll 1$). Here, we only discuss the latter, but this does not mean that the possibility of a round beam should be excluded.

Equation (1) determines the beam current which is needed to obtain the desired luminosity. In order to decrease the beam current, the tune shift parameter should be high and β_y^* should be low. We choose for both beams $\xi_x = \xi_y = 0.05$, which is close to the maximum value achieved by the existing machines. The minimum β_y^* , on the other hand, is determined by the insertion design of the IP and the

chromaticity correction system; a more important relation, though, is its ratio to the bunch length, σ_z . If the ratio β_y^*/σ_z becomes lower than 1, there appear not only a geometrical loss of the luminosity, but also a decrease in the maximum tune shift due to the synchrotron-betatron resonances. Therefore, a small β_y^* requires a short bunch, which, in turn, requires a high accelerating voltage. Our choices that $\beta_y^*=1$ cm and that

$$\beta_y^*/\sigma_z = 2 \quad (5)$$

seem to be the minimum achievable, considering the above-mentioned conditions. We thus determined the beam currents, $I_1=2.6$ A and $I_2=1.1$ A, for the 3.5- and the 8-GeV rings, respectively.

The next important parameter to discuss is the bunch spacing, S_B . The number of particles/bunch is a function of S_B ,

$$N_i = \frac{I_i S_B}{ec}. \quad (6)$$

In order to determine how to treat this parameter, it is necessary to examine which machine characteristics depends on S_B . First, Eqs. (3) and (6) give the horizontal emittance,

$$\varepsilon_x = \frac{r_e I_{3-i} S_B}{2\pi c e \gamma_i \xi (1+r)}. \quad (7)$$

In an electron storage ring which only contains normal cells as the source of synchrotron radiation, the emittance is given by

$$\varepsilon_x \approx \frac{2R_A}{\nu_{xi}^3} \sigma_{\varepsilon i}^2, \quad (8)$$

where R_A , ν_{xi} and $\sigma_{\varepsilon i}$ are the average radius, the horizontal tune of the arc and the relative energy spread. The accelerating voltage, V_{ci} , is written as

$$V_{ci} = \frac{cC E_i \alpha_{pi} \sigma_{\varepsilon i}^2}{e\omega_{RF} \sigma_z^2}, \quad (9)$$

where C , E_i , α_{pi} , and ω_{RF} are the circumference, the beam energy, the momentum compaction factor, and the RF angular frequency. We also know that

$$\alpha_{pi} \approx \left(\frac{1}{\nu_{xi}}\right)^2 \frac{2\pi R_A}{C} \approx \left(\frac{\varepsilon_x}{2R_A \sigma_{\varepsilon i}^2}\right)^{2/3} \frac{2\pi R_A}{C}, \quad (10)$$

where we have used (8). The energy spread is given by

$$\sigma_{\varepsilon i} = \frac{55}{64\sqrt{3}} \frac{\gamma_i^2}{\rho_i} \lambda_e, \quad (11)$$

where ρ_i and λ_e are the bending radius and the Compton wavelength of an electron. We assume that $R_A = a_i \rho_i$. Using (9), (10) and (11), we obtain

$$V_{ci} = \frac{2\pi c E_i}{e \omega_{RF} \sigma_z^2} \left[\left(\frac{55}{64\sqrt{3}} \lambda_e \right)^{1/2} \frac{\gamma_i \varepsilon_x}{2} \right]^{2/3} a_i^{1/3}. \quad (12)$$

If we determine ε_x by (7), the accelerating voltage, V_{ci} , becomes a function of S_B . We must therefore shorten the bunch spacing to make the voltage low. Note that V_{ci} depends on neither ρ_i nor C explicitly.

At the KEK B-Factory, people are thinking of making use of the same RF system as that used in TRISTAN, which has the frequency, ω_{RF} , of $2\pi \times 500$ MHz. Thus, shortest bunch spacing is 0.6 m. A finite crossing angle at the IP is necessary; otherwise, separating the two beams at the extra-collision points in such a short spacing is impossible. Difficulties involving the crossing angle, excitation of the synchrotron-betatron resonances, will be solved by using the crab-crossing scheme.^{[1][2]} It is not only easy, but efficient to fill every bucket of the rings during injection from the linac and the TRISTAN AR, compared to partial filling. Another argument concerning short bunch spacing is a difficulty involving the feedback system for coupled-bunch instabilities; the damped cavities however will essentially cure these instabilities. We have presently reached a conclusion: If we use the flat-beam scheme, $S_B=0.6$ m is the best solution for the KEK B-Factory. Equation (7) implies that the short bunch spacing means a low emittance of the ring; the emittance becomes $\varepsilon_x \approx 2 \times 10^{-8}$ m using this design.

After we determine the bunch spacing, the bending radius, ρ_i , is the only one free parameter that we can choose. Figure 1 shows several parameters which depend on ρ_2 (8 GeV). A smaller ρ makes the circumference shorter, but increases the energy spread, which makes the dynamic aperture of the ring smaller and also decreases the effective cross section. The energy spread becomes especially important if we must use the same ring both for 8- and 12-GeV experiments. From this figure, we should use $\rho_2 \approx 100$ m; otherwise the energy spread of 12 GeV beam becomes too high. In that case, the circumference becomes about 1200 m, if we set $a_2 = 1.3$ and $C = 2\pi R_A + 400$ m.

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Figure 1: The dependence of circumference and energy loss upon the bending radius.

Design of the Lattice for the KEK B-Factory

II. Koiso and K. Oide

1. Beam Parameters

The KEK B-Factory is an asymmetric double-ring collider of 8×3.5 GeV with a design peak luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. The main features of the beam parameters are a flat beam ($\varepsilon_y/\varepsilon_x = 0.01$), small beta function ($\beta_y^* = 1 \text{ cm}$), short bunch spacing ($S_b = 0.6 \text{ m}$) with the crab-crossing scheme[1] and low emittance ($\varepsilon_x = 1.9 \times 10^{-8} \text{ m}$). The parameters are listed in Table 1. The considerations used to determine these parameters are given in the paper #1 of this report.

We plan to build the B-Factory in two steps. In the first step, we will use a head-on collision scheme and long bunch spacing ($S_b = 3 \text{ m}$). The peak luminosity of the first step will be $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. In the second step we will use the crab-crossing scheme with a large crossing angle to achieve $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. According to a recent study of the long-range beam-beam force[2], a small crossing-angle collision without crab cavities is also under investigation as a promising collision scheme for the second step. The machine parameters for both steps remain essentially unchanged, except for the bunch spacing and the total current. The same lattice will be used for both steps, with minor changes around the interaction point (IP). Figure 1 shows a schematic view of the rings which are to be placed in the same horizontal plane. The lattice and the optical functions of the rings are shown in Fig. 2.

The high-energy ring (HER) and the low-energy ring (LER) have the same circumferences, emittances, and the beta functions at the IP. This gives similar sizes of the normal cells, the betatron tunes, and the energy spreads to both rings. The energy spreads are set to be less than 0.08% in order to provide a sufficient $\Upsilon(4S)$ yield as well as a good constraint of the total energy on event reconstruction. The damping time becomes twice as long in LER as in HER if only the radiation from the arc is taken into account. We are preparing wigglers with a total length of about 60 m for both rings to obtain a wide range of flexibilities. By tuning the dispersions in the wiggler sections, we can control the damping time and the emittance independently.

We allow a space of 50 mm $\times$ 100 mm for a beam duct of the rings in the arcs in order to attain a large conductance which ensures uniform distributed pumping speed (See the paper #13 of this report). The magnets of HER are designed to be operated up to 12 GeV with this aperture.

2. Chromaticity Correction

Table 1: Main parameters of the KEK B-Factory.

Energy	E	3.5	8.0	GeV
Circumference	C	1273		m
Luminosity	$\mathcal{L}$	$1 \times 10^{34} (2 \times 10^{33})$		$\text{cm}^{-2}\text{s}^{-1}$
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_e	7.9×10^{-4}	7.2×10^{-4}	
Bunch spacing	S_B	0.6 (3.0)		m
Particles/bunch	N	3.3×10^{10}	1.4×10^{10}	
Emittance	$\varepsilon_x/\varepsilon_y$	$1.9 \times 10^{-8}/1.9 \times 10^{-10}$		m
Synchrotron tune	ν_s	0.047	0.051	
Betatron tune	ν_x/ν_y	27/25	26/25	
Momentum 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		
Longitudinal threshold	Z/n	0.16	0.88	Ω
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 in $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$.

The main problem in the design of the lattice is the chromaticity correction of the ring. In order to correct the large chromaticity of the final quadrupoles, we examined two schemes of the chromaticity correction using a test lattice of LER. The first one is six-family interlaced sextupoles with 60° normal cell, and the second one is non-interlaced pairs of sextupoles with 90° normal cell and a $-I$ transformation between sextupoles in a pair[3]. In the latter case, 26 pairs of sextupoles were installed in the ring and grouped into eight families. The strengths of the sextupoles are determined by fitting $\beta_{x,y}$ and $\alpha_{x,y}$ at the IP and the betatron tunes simultaneously at four off-momentum points which have momentum deviations of $-dp$, $-\frac{1}{2}dp$, $+\frac{1}{2}dp$ and $+dp$. The momentum bandwidth dp was typically taken to be $\sim 1\%$. In this fitting, we used a computer code SAD developed at KEK[4].

Figure 3 shows a comparison of the horizontal dynamic apertures of both schemes as a function of the energy deviation of a test particle. This aperture was measured

by particle tracking in 6 dimension using SAD. The initial values of the horizontal displacement and the energy deviation of test particles which survived 1000 turns were plotted in the figure. The initial vertical displacement was chosen to be 1/10 of the horizontal one in this tracking. This result clearly shows the merit of the non-interlaced scheme, especially in the transverse direction of the dynamic aperture. The critical value of the dynamic aperture is 1.2×10^{-5} m at 0.3% momentum deviation, which is determined by the amplitude at the injection time. From this figure, we have concluded that only the non-interlaced scheme satisfies the requirement.

The Touscheck lifetime is determined by the momentum acceptance. A larger acceptance is required in LER than in HER. To make the dynamic aperture large in the longitudinal direction, it is effective to increase the number of families of the sextupoles. By increasing the number of sextupole families up to 26, we actually achieved 1.6% momentum acceptance in LER, which corresponds to a Touscheck lifetime of 7.5 hours.

The merit of the non-interlaced scheme is based on a cancellation of the geometric aberrations of the sextupoles by the $-I$ transformation in a pair[3]. This scheme may therefore be sensitive to the errors of the magnets in the $-I$ transformer. Generally speaking, if there are strength errors of the quadrupoles of the arc, the $-I$ transformation breaks down. The strength errors of the sextupoles make the cancellation incomplete. These errors thus decrease the dynamic aperture. Our present design of the lattice, however, is not so sensitive to the strength errors of the magnets. Figures 4(a) and 4(b) show comparisons of the dynamic aperture with and without the strength errors of the quadrupoles and sextupoles. Note that a peak shift is induced by the dilation of the path length through a large-amplitude betatron oscillation. With Gaussian errors of 0.1% for the strength of the quadrupoles and 0.2% for the sextupoles, the dynamic aperture of the ring does not change significantly.

We also examined the dependence of the dynamic aperture on the number of interaction points. The results are shown in Fig. 5. If we have 2 IP's in a ring with the same arc size as in the present design, the dynamic aperture becomes about half. This result suggests that we need a larger arc and circumference in order to obtain more IP's.

3. Compensation of the Solenoid Field Effect

One of the most important points regarding the design of the lattice around the IP is to compensate for the x - y coupling effect generated by the solenoid of the detector. A unique problem for an asymmetric collider is that the design orbits cross the solenoid with a finite angle, both in the crab-crossing (due to the crossing angle) and the head-on collision cases (due to the separation bending magnets in the solenoid). We must therefore correct the dispersions generated by the solenoid and the separator, as well as the coupling elements of the transfer matrix.

Such a correction is achieved by adding at least four skew quadrupoles and several bending magnets on each side of the IP. All four coupled elements of the transfer matrix from the arc to the IP and the dispersions ($\eta_x, \eta'_x, \eta_y, \eta'_y$) at the IP are cancelled. Because of the high ($B = 1$ T), long ($L = 2.2$ m) field of the solenoid, we cannot use a perturbative method to determine the strength of skew quadrupoles, especially for LER. For this purpose, we have improved SAD to solve corrections for the coupling and matching of the linear optics simultaneously.

Figures 6 and 7 show the lattice and the optical functions around the IP for the head-on collision and the crab-crossing, respectively. In the head-on case, the lattice is rather different on each side of the IP due to the fact that a septum magnet for beam separation is placed only at the outgoing side. If necessary, we can detune β^* without changing the strengths of the magnets in the colliding insertion (See the paper #5 of this report concerning the colliding insertion).

In the case of the crab-crossing with a crossing angle of ± 25 mrad, the lattice is simpler since there are no common magnets used in the colliding insertion. The final quadrupoles are placed 1.8 m from the IP in LER and 2.2 m in HER. The design orbit crosses the solenoid with 50 mrad only in HER. The horizontal phase advance from the IP to the crab cavity is set $3/2\pi$ and β_x at the crab cavity about 100 m. The lattice between IP and the crab-cavity is the same on each side of the IP. We prepared six quadruples between the arc and the crab cavity so that we can detune β^* without changing the magnet strengths between the pair of the crab cavities. Figure 8(a) and (b) show the dynamic aperture of HER and LER in the crab-crossing scheme.

Although, in the current design, we do not have any special corrector for the chromaticity of the coupled elements, the dynamic aperture is still sufficiently large to clear the aperture required at injection and to guarantee a long Touscheck lifetime as shown in Figs. 4 and 8.

Summary

We designed the lattice consistent with a peak luminosity of $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ in a head-on collision scheme and $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ in a crab-crossing scheme. The lattice has a sufficient dynamic aperture to satisfy the requirements for injection and the Touscheck lifetime.

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Figure Captions

Fig. 1 A schematic view of the KEK B-Factory rings.

Fig. 2 Optical functions of (a) HER and (b) LER.

Fig. 3 Comparison of the horizontal dynamic aperture for the two methods of the chromaticity correction.

Fig. 4 Comparison of the dynamic aperture with and without strength the errors of magnets for (a) HER and (b) LER.

Fig. 5 Dependence of the dynamic aperture on the number of interaction points.

Fig. 6 Optical functions around the IP in the head-on scheme for (a) HER and (b) LER.

Fig. 7 Optical functions around the IP in the crab-crossing scheme for (a) HER and (b) LER.

Fig.8 Dynamic apertures of (a) HER and (b) LER in the crab-crossing scheme.

Figure 1 A schematic view of the KEK B-Factory rings.

Figure 2 (a) Optical functions of HER.

Figure: 2 (b) Optical functions of LER.

Figure: 3 Comparison of the horizontal dynamic aperture for the two methods of the chromaticity correction.

Figure 4: Comparison of the dynamic aperture with and without the strength errors of magnets for (a) HER and (b) LER.

Figure 5: Dependence of the dynamic aperture on the number of interaction points.

Figure 6: (a) Optical functions around the IP in the head-on scheme for HER.

Figure 6: (b) Optical functions around the IP in the head-on scheme for LER.

Figure 7 (a): Optical functions around the IP in the crab-crossing scheme for HER.

Figure 7 (b): Optical functions around the IP in the crab-crossing scheme for LER.

Figure 8: Dynamic apertures of (a) HER and (b) LER in the crab-crossing scheme.

Beam-Beam Effects

K. Hirata

1. Introduction

The beam-beam effects have been studied extensively for a long time [1], and we have accumulated a large amount of knowledge concerning symmetric, single-ring colliders. The KEK B-Factor, however, is a high luminosity, asymmetric, two-ring collider and have the following challenging characteristics concerning beam-beam effects:

1. The expected beam-beam tune-shift, ξ , is as high as 0.05;
2. e^+ and e^- beams circulate in different rings with different energies (3.5 GeV for e^+ and 8 GeV for e^-). Two beams, therefore, can have quite different parameters;
3. All of the buckets are filled with the beam in order to maximize the luminosity.

In section 2 we discuss the maximum value of ξ . Section 3 deals with issues concerning energy transparency. Section 4 discusses the effect of peripheral collisions.

2. Maximum Value of ξ

The beam-beam force is characterized by the following three parameters [2]:

$$\xi_z = \frac{N_* r_e}{\gamma} \frac{\beta_z}{2\pi\sigma_z(\sigma_x + \sigma_y)},$$
$$R_1 = \frac{\sigma_s}{2\beta_z}, \quad \text{and} \quad R_2 = \frac{\varepsilon_z}{2\sigma_\varepsilon\beta_z}.$$

Here, z refers to either the horizontal (x) or vertical (y) direction. Symbols mean that:

- N_* ; the number of particles in a bunch of the other beam,
- σ_x, σ_y ; the beam size at the interaction point (IP),
- β_x, β_y ; the beta-function at the IP,
- $\varepsilon_x, \varepsilon_y$; the emittance,
- σ_ε ; the momentum spread,
- σ_s ; the bunch length,
- γ ; the beam energy in a unit of the electron mass,
- r_e ; the classical electron radius.

R_1 measures an influence of the longitudinal motion to the transverse one, while R_2 measures an influence of the transverse motion to the longitudinal one. In addition to the above-mentioned three parameters, tunes (ν_x , ν_y and ν_s), and the damping period [3],

$$T_e = \frac{\text{longitudinal damping time}}{\text{revolution period}}, \quad (1)$$

are also important. In the KEK B-Factory, R_2 is very small compared to one so that we can ignore it.

We can classify the beam-beam effect into two regions according to the value of R_1 :

1. Transverse Region ($R_1 \leq 0.1$)

In this region we only need to consider betatron oscillations, neglecting longitudinal motions. This case has been studied well. There is an empirical law for the maximum value of ξ , ξ_{limit} , which fits the data surprisingly well [4]:

$$\xi_{limit} \simeq 230 \frac{1}{\sqrt{\gamma T_e}} \quad (2)$$

2. Longitudinal Region ($R_1 \geq 0.1$)

In this region, we cannot ignore synchrotron oscillations. Milton claimed that the maximum value of the disruption parameter defined by

$$D_z = 4\pi\xi_z \frac{\sigma_s}{\beta_z} \quad (3)$$

is almost universal among various rings [5]. On the other hand, we made a simulation on the basis of Ref. 2. The result is that ξ_{limit} ¹ is a function of R_1 and that

$$\xi_{limit}^2 R_1 (\propto \xi_{limit} D_{limit}) \quad (4)$$

is almost constant and a weak function of T_e ($\xi_{limit}^2 R_1$ becomes larger if T_e becomes smaller). Figure 1 summarizes the result of the simulation.

The KEK B-Factory case is classified into the longitudinal region. Table 1 lists the experimental observations [6] together with the KEK B-Factory values.

Our goal of $\xi = 0.05$ is close to the maximum ever attained. It might be necessary to decrease σ_s slightly and to make T_e smaller in order to achieve this goal; both require, however, larger accelerating voltages.

¹In this simulation, ξ_{limit} is defined as the value of ξ when the beam size σ becomes twice as large as that of the initial value σ^0 .

Figure 1: The maximum value of the nominal beam-beam parameter, η , as a function of R_1 . η is defined by $\eta_z = \frac{N_s r_e}{\gamma} \frac{\beta_z}{2\pi\sigma_z^0(\sigma_x^0 + \sigma_y^0)}$, where σ_z^0 is the beam size without the beam-beam interaction. The maximum value of η is defined as that when σ becomes twice as large as σ^0 . This simulation was made for a round beam with $\nu_x = 0.15$ and $\nu_s = 0.085$. The solid line is for $T_\epsilon = 2000$ and the dashed line for $T_\epsilon = 200$. Data from an experiment at CESR [5] are shown by $\times$.

Table 1: Comparison of experimental observations with the KEK B-Factory case.

	R_1	ξ_{limit}	D_{limit}	$\xi_{limit}D_{limit}$
SPEAR 1.9	0.15	0.056	0.21	0.012
VEPP-4	0.16	0.06	0.24	0.0144
CESR 1b5.5	0.40	0.028	0.28	0.008
PEP 1jp	0.21	0.05	0.26	0.013
B-Factory(KEK)	0.25	0.05	0.314	0.0157

(The data of VEPP-4 are taken from Ref. [5].)

3. Energy Transparency

The beam-beam interaction limits the performance of e^+e^- colliders through a flip-flop phenomenon. In order to make the threshold of this phenomenon as high as possible, it seems appropriate to make both beams identical. From a beam-beam point of view, two beams are regarded as identical if their ξ , T_c , R_1 , R_2 and tunes are the same. In our case, as stated before, R_2 is not important. From the condition that ξ and R_1 are equal for both beams, β , ε and σ_s should be made equal for both beams. We have set all parameters listed below, except for T_c , equal for both beams. By the use of wigglers, we can also make T_c the same² for both beams. The other parameters such as ν_x , ν_y , ν_s and σ_c allow small differences between the beams.³

Table 2: Parameters made equal in both beams.

Beta function at the IP	β_x, β_y	100, 1	cm
Horizontal emittance	ε_x	1.9×10^{-8}	m
Vertical emittance	ε_y	1.9×10^{-10}	m
Bunch length	σ_s	5	mm
Beam-beam parameter	ξ_x, ξ_y	0.05	
Longitudinal damping period	T_c	3800 (e^+), 2000 (e^-)	

Note that it is not an established fact that identical beams give the highest possible luminosity. There might be some other clever way to maximize the luminosity. Further investigation is necessary to determine the optimum condition.

4. Peripheral Collisions

In order to fill all of the buckets to achieve a high luminosity in the second step of the KEK B-Factory, we should adopt a scheme where two beams collide at a finite angle⁴, since the bunch spacing, S_B , is only 0.6 m and we cannot install

²The importance of T_c is one of the issues. The result of a simulation [7] and an independent result of a theory [8] imply that, if T_c is different between beams, the luminosity is maximum when

$$\frac{\xi_-}{\xi_+} \sim \sqrt{\frac{T_c^+}{T_c^-}}.$$

Otherwise, the beam blow-up is asymmetric between beams. This means that T_c should be set equal in order to set $\xi_- = \xi_+$.

³As long as the number of interaction points is one, tiny differences between tunes are not dangerous [9,10]. It is not difficult to make transverse tunes equal between beams.

⁴We have chosen a flat beam. The reason is as follows: A flat beam can enjoy horizontal crossing; the long-range beam-beam effect is less serious because of the small value of β_x at the peripheral collision points. A round beam of small β_r^* seems to have a much stronger effect there.

any separation device necessary to make head-on collisions. At points $n \times S_B/2$ (n is an integer) distant from the IP, close encounter of bunches takes place and a long-range force works between the bunches (We call this encounter a peripheral collision). The crossing angle must be sufficiently large to make the two beams separate quickly so that the beams should not be much affected by the long-range beam-beam force. We carried out a simulation, where we assumed that a bunch has a rigid Gaussian shape [11]. The result shows that, due to the long-range beam-beam force, coherent betatron oscillations are excited and that if the crossing angle, φ , is too small, the oscillations become chaotic. If we assume that six peripheral collision points exist in each side of the IP,

$$\varphi = 3 \text{ mrad}$$

is the minimum angle necessary to avoid the effect.

From the practical point of view, two beams must be sufficiently apart at the place a few meters from the IP so that each beam can enter an independent beam pipe. It is also well known that beams suffer from the synchrotron-betatron resonance if they collide at a large angle [12]. In order to avoid this problem, we must adopt a crab-crossing scheme [13]. We must, therefore, adopt one of the following two options:

(1) Crossing at a small angle:

In this option, φ is a few mrad. A separation dipole magnet (for example, 0.6 T magnets located between the points 0.5 m and 1.5 m from the IP) in each side of the IP can separate the beams quickly so that beams can enter independent beam pipes at the points a few meters from the IP. This scheme has an advantage that we do not require any crab cavities; it has a disadvantage, however, that the separation dipole magnets complicate the IR design (see the papers #5 and #7 of this report).

(2) Crab crossing:

If φ is a few $\times 10$ mrad, we do not need any separation dipole magnets. This case requires crab crossing and crab cavities should be installed around the IP (see paper #12 of this report). Koiso and Oide generalized Yokoya's multiparticle tracking code to study the effects of collisions at an angle [14]. They claim that the crab-crossing scheme works well without any severe requirement on tolerances.

Concerning these options, we add a few comments below:

1. In both schemes, the effects of peripheral collisions were studied only in terms of a rigid Gaussian model with betatron oscillations only. The energy modulation due to the long-range beam-beam force has not been taken into account. (The effect is proportional to $\sin \varphi / \varphi$, which is almost constant for small φ .)

2. The simulation of Koiso and Oide has been performed for very strong damping ($T_c=500$) so that the results can be over optimistic. Also, the treatment of the beam-beam force in the code is not completely symplectic. For safety, it should be made symplectic according to the prescription given in Ref. 2.
3. Neither the crab cavity nor the separation bending magnet have not yet been tested in a real accelerator.

In the first step of the KEK B-Factory where we adopt a head-on collision scheme and fill every fifth bucket with the beam, the proposed beam-separation system (see paper#5 of this report) separates two beam orbits so quickly that the long-range beam-beam force does not affect the beam stability.

5. Summary

We have discussed issues involving the KEK B-Factory from the beam-beam point of view. The following is a summary:

1. We assume that the maximum beam-beam tune shift is 0.05. This value corresponds to the disruption parameter of 0.31, which is close to the highest value ever attained.
2. We showed that making the parameters, ξ , β , ε , σ_s , and T_c , identical for both beams is appropriate for attaining maximum energy transparency.
3. In the case where we fill every bucket with beam, we should adopt one of the following two options in order to prevent the long-range beam-beam force from affecting the beam stability.
 - beam crossing at a few mrad without crab cavities, or
 - beam crossing at a few $\times 10$ mrad with crab cavities.

The former option requires separation bending magnets close to the IP.

References

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Single Bunch Instability

K. Satoh and K. Oide

The feature of the present design is a low β_y^* of 1 cm with a relatively large beam-beam tune shift limit of 0.05. An understanding of the beam-beam interaction tells us that the bunch length has to be much less than β_y^* in order to reach the high tune shift limit. Therefore, it is very important to estimate the bunch lengthening effect and to know whether a 5 mm bunch is feasible.

We expect that the impedance sources will be RF cavities, bellows with an inner shield and radiation masks near the interaction point. Since precise designs for these components have not been fixed, we estimated the impedance with their model structures. An impedance calculation was performed with TBCI, where cylindrical symmetry was assumed. Figure 1 shows the model structures, in which a KEK PF cavity is assumed as a damped-cavity model.

Table 1 describes the loss parameters for a 5 mm bunch and the expected numbers of components. Notice that the impedance of the mask is calculated for a model mask having cylindrical symmetry. The real mask would be attached on one side, or both sides, of the beam tube wall and would interrupt only a part of the electromagnetic field carried by a traveling bunch. While several masks are required near the detector, we will replace them with one model mask in the calculation, considering the overestimation of the mask impedance.

Table 1: Loss parameters of the low-energy ring.
 $\sigma_z = 5 \text{ mm}$

	$k_L(V/C)$	N	$Nk_L(V/C)$
Cavity	6.8×10^{11}	40	2.7×10^{13}
Shielded bellows	2.9×10^{10}	400	1.2×10^{13}
Mask	5.9×10^{11}	1	5.9×10^{11}

For predicting the bunch lengthening threshold we used a program developed by K.Oide and K.Yokoya.^[1] The program analyzed the stability of the bunch with the Vlasov equation, including the potential well distortion. The Vlasov equation is solved by expanding the density distribution with base functions in two-dimensional synchrotron phase space. This program is consistent with the particle tracking method, and explains the bunch lengthening in the TRISTAN main ring fairly well. For this reason we believe in its reliability.

The program needs to be given the wake field produced by a point charge. We approximate the wake field with the wake potential of a 1.25 mm bunch, much

shorter than 5 mm. The estimation was made for a low-energy ring because bunch lengthening is more severe than in a high-energy ring. Figure 2 shows the approximate total wake field of each component. The cavity impedance is capacitive, whereas the shielded bellows and the masks are inductive and harmful for the bunch lengthening effect.

The program predicts that the threshold current of bunch lengthening would be five times that needed in the present design, as shown in Fig.3. Although the impedance estimation is not complete, we conclude, considering the large safety factor of five, that a 5 mm bunch is feasible.

Finally, we add a comment concerning the fast head-tail instability in the transverse direction. The transverse impedance was also calculated with TBCI for the same model structure. The betatron tune shift in the low-energy ring would be of the order of 0.001, which is much smaller than the synchrotron tune of 0.5. Therefore, the fast head-tail instability is not dangerous in the B-factory.

Reference

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Figure 1: Model structures for the calculation of the impedance.

Figure 2: The wake functions for three types of impedance source.

Figure 3: The predicted bunch length as a function of the number of particles/bunch.

Insertion Design

K. Satoh

1. General Parameters

The present scenario of the KEK B-Factory is that the collider starts operation with the head-on option; after the development of crab cavities it reaches the final goal with the crab crossing scheme. This report describes only the insertion design for head-on collisions. The beam and optics parameters are given in Table I. The design luminosity of this option is $2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$, which is one fifth of the design goal of $1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$. The reduction is only due to the fact that one out of every five buckets is filled with beam, whereas every bucket is to be to achieve the goal luminosity. The other parameters are the same for both options.

Table I: Head-on Option Parameters.

	HER	LER
Energy	8 GeV	3.5 GeV
$\mathcal{L}$	$2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$	
β_x^* / β_y^*	1 m / 1 cm	
Current	0.22 A	0.52 A
Bunch Length	0.5 cm	
Bunch Spacing	3 m	
Emittance	$1.9 \times 10^{-8} \text{m}$	
Emittance Ratio	0.01	

2. Constraint in the Design

Several kinds of constraints have been considered in the insertion design. The first is beam separation. From the viewpoint of physics experiments the beam tube radius at the interaction point(IP) has to be sufficiently small. If the synchrotron radiation from an incoming beam must not hit the IP tube as well as masks very close to IP, the deflection angle produced by a separation bend can not be a free parameter and is restricted by the tube radius. From the accelerator point of view, however, a smaller separation angle moves the defocussing quadrupole magnets farther from IP and, hence, increases the chromaticity. The insertion design is a compromise between the two opposite sides.

The accelerator components inside a detector must not interfere with experiments. The components should be inside a conical region, spreading by 300 mrad

from the center axis. Since the detector has a solenoid field of 1T (4 m long in total) no ferromagnetic material is allowed there unless the field is eliminated, for example, by compensation coils.

The last constraint is related to injection. At present, we plan to inject beams directly into the colliding optics, not into another injection optics. We suppose that switching optics between the two without losing the stored current is very difficult and hopeless. Therefore, the aperture of the insertion has to be sufficiently wide in accordance with the acceptance required for injection, which is temporarily assumed to be $1.2 \times 10^{-5}\text{m}$.

3. Design Parameters

The insertion layout is shown in Figs.1 and 2, and magnet parameters are listed in Table II. Fig.3 shows the linear optics of both rings. The solenoid field effect is not taken into consideration in the figure. The x - y coupling due to the solenoid field and its compensation by skew quadrupoles are treated in the paper#2 of this report. In order to decrease the synchrotron radiation from the incoming beam and to make sufficient separation quickly between the two orbits, the optics are no longer symmetric with respect to IP. Notice that no vertical bend element is used and both orbits lie on a plane near IP.

Beam separation is achieved by permanent bending magnets. The field strength of the permanent bending magnet is proportional to the logarithm of the ratio of the outer and inner diameters of the core, as well as the remanent field strength of the magnetic material.^[1] Since both the outer and inner diameters are restricted by the beam duct and the acceptance of the detector, the bending field is limited below a low value, especially in the closer region to the interaction point. In this report the bending magnet described is made up of four sets of magnetic cores, each of which has the maximum ratio of the core diameters. In order to reduce the leakage field outside the magnet, each core is divided into 16 segments.

On both sides of IP the orbit of the incoming beam goes through the center of a defocussing superconducting quadrupole QCD. A defocussing QC3H is a half quadrupole magnet and, hence, can be inserted closely enough to IP. The half magnet focuses vertically and deflects the HER beam outwards, helping in orbit separation. The outgoing beam orbit is deflected away from the other by septum magnets, SEPH and SEPL.

How to choose the deflection angle of the separation bend is a compromise between the size of the IP duct and the chromaticity. The deflection angle is determined by the condition that synchrotron radiation from incoming particles on the LER center orbit must be confined to within 27 mm from IP in the horizontal direction. The size of the IP duct is 60 mm, 35 mm outside and 25 mm inside, and about 30 mm in full height. The large chromaticity produced in the insertion is

compensated for by non-interlaced sextupole corrections. This fact was confirmed using a particle-tracking method in model optics having almost the same chromatic condition (see the paper #2 of this report).

We plan to insert superconducting compensation coils to reduce the solenoid field effect. Then, the solenoid field would be eliminated, except for within about 1.1 m from IP. The compensation coil is to be contained in the same cryostat of QCD (see the paper #6 of this report).

Reference

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Table II: Insertion Magnet Parameters (Head-on Option, Ver.7.3).

element	parameters			
Free Space	0.3 m $\times$ 2			
Separation Bend	<i>Permanent</i>			
	Field	ID	OD	L
#1	0.181 T	120 mm	160 mm	200 mm
#2	0.459 T	130 mm	270 mm	200 mm
#3	0.627 T	140 mm	380 mm	200 mm
#4	0.690 T	160 mm	480 mm	200 mm
QCD	<i>Superconducting</i>			
	Gradient	16.3 T/m		
	Useful Radius	55 mm		
	Length	0.5 m		
QC3H	<i>Half Quadrupole 20 mm Offset</i>			
	Gradient	14.2 T/m		
	Bore Radius	55 mm		
	Length	0.6 m		
QC4H	<i>Normal Iron</i>			
	Gradient	9.9 T/m		
	Bore Radius	80 mm		
	Length	0.6 m		
QC2L	<i>Normal Iron</i>			
	Gradient	8.8 T/m		
	Bore Radius	70 mm		
	Length	0.3 m		
SEPH	<i>Septum magnet HER</i>			
	Field	0.70 T		
	Length	1.9 m		
	Angle	50.0 mrad		
SEPL	<i>Septum magnet LER</i>			
	Field	0.47 T		
	Length	0.7 m		
	Angle	28.0 mrad

Figure 1: Insertion layout, (a) a whole view and (b) a close view.

Figure 2: Linear optics of LER and HER. The dispersion function is not true since offset quadrupoles (QCD and QC3H) are not treated correctly.

Compensation of the Solenoid Field along the Beam Line

K. Tamai and K. Tsuchiya

In the present scheme for achieving a high luminosity, the bunch spacing is so small that beam separation must be carried out immediately after a collision, even while still inside the solenoid field of the detector. Thus, the beam axis deviates from the direction of the solenoid field, causing a disturbance to the beam optics. We have tried to reduce the solenoid field along the beam axis to minimize this effect. Usually, the magnetic field can be reduced either by applying an opposite field, or by shielding with iron. A more exotic method using the Meisner-effect shielding might be possible in principle, although it is not technically well established. Shielding with iron is not possible for 1 Tesla strength, even if all of the available space around the beam pipe is filled with iron. Thus, a method using a compensation magnet is the only possible way.

We are exploring a scheme in which a superconducting compensating magnet (C-magnet) is placed inside the same cryostat as that used for the quadrupole magnet nearest to the interaction point (Q-magnet). The axis of the Q-magnet is aligned along the beam axis: one side for the high-energy beam and the other side for the low-energy beam. The axis of the C-magnet, on the other hand, is aligned along the solenoid axis. Figure 1 shows the arrangement. The dimensions of the Q-magnet and the C-magnet, which satisfy the beam optics requirement and dimensions of the cryostat, are given in Table 1.

Table 1. Dimensions of the Q-magnet, the C-magnet and the cryostat.

	Radial dimensions		z-dimension
Cryostat	inner radius	10.0 cm	110~225 cm
	maximum outer radius	32.0 cm	
Q-magnet	inner radius	12.5 cm	150~200 cm
	outer radius	15.0 cm	
C-magnet	inner radius	21.0~24.0 cm	120~210 cm
	thickness	1.0 cm	

The calculated magnetic field based on this arrangement is shown in Fig. 2: (a) B_z on the solenoid z -axis, and (b) B_r on the LER axis. It can be seen that the B_z component is mostly cancelled for z greater than 150 cm and decreases to a level of 10 Gauss in the Q-magnet region. However, the cancellation of the B_z component induces an appearance of the radial B_r component of the order of several Gauss near the Q-magnet and about 300 Gauss near the edge of the C-magnet coil. The

deformation from a uniform solenoid field due to the presence of the C-magnet is shown in Fig. 3. We believe that this level of deformation does not cause any problem in the tracking analysis.

A potential problem to the detector comes from a leakage field from the Q-magnet in the area of RICH, the Ring Image Cherenkov Counter, mounted on the pole-tip iron. The amount of leakage strongly depends on the inner radius of Q-magnet (Fig. 4). For example, by changing it from 12.5 cm to 11.5 cm we can reduce the leakage by 35%. It is thus important to come up with a design of Q-magnet with a smaller inner radius and still satisfying the beam optics requirement.

Figure Captions

Fig. 1 A plan view of the interaction region. The $\theta = 300$ mrad line divides the region available for the accelerator and for the detector.

Fig. 2 Calculated magnetic field with a solenoid, Q-magnet, and the C-magnet: (a) B_z on the solenoid axis and (b) B_r along the LER axis.

Fig. 3 Equal-field lines inside the detector volume.

Fig. 4 Leakage field from the Q-magnet when operated at 17 T/m.

Figure 1: A plan view of the interaction region. The $\theta = 300$ mrad line divides the region available for the accelerator and for the detector.

Figure 2: Calculated magnetic field with a solenoid, Q-magnet, and the C-magnet: (a) B_z on the solenoid axis and (b) B_r along the LER axis.

Figure 3: Equal-field lines inside the detector volume.

Figure 4: Leakage field from the Q-magnet when operated at 17 T/m.

Masking System and Background Estimation at the Interaction Region

S. Uno

1. Introduction

There are two sources of beam background in any e^+e^- collider experiment. One source is synchrotron radiation from the bending magnets and quadrupole magnets. The synchrotron radiation photons produce signals in the detector via both the photoelectric effect and Compton scattering. If these rates become too high, true tracks cannot be reconstructed. Another problem involving radiation damage may occur due to a large dark current. Photons with an energy greater than 100 keV produce signals in the time of flight (TOF) counters, causing severe problems in the trigger rate. Another source of background comes from spent electrons (off-momentum beam particles generated by interactions with residual gas) which hit the beam pipe near the interaction region because of over-bending (over-focus) at the nearest bending magnets (Q-magnets). When this happens, electromagnetic showers, or sometimes hadronic showers, are generated along with many daughter particles. The charged particles in such showers produce curler tracks inside the inner part of the detector. Photons, on the other hand, hit the TOF counter and the shower counter primarily in the small-angle region. Charged tracks originating from a hadronic shower may have a large transverse momentum, thus causing fake triggers. To reduce such background, careful design of the masking system is important. We have designed a masking system based on the insertion design shown in Fig. 1.

2. Synchrotron Radiation

Although the critical energy of synchrotron radiation is rather low in the proposed B-factory, 10~50 keV, the number of photons with energy greater than 5 keV is as large as 10^{10} per beam crossing; the fraction of these entering the detector acceptance through scattering at the edges of the masks or scattering along the beam pipe wall far from the interaction region becomes non-negligible. They must be reduced by a set of several masks and the optimized radius of the beam pipe. Figure 2 shows the cross section of the beryllium beam pipe surrounding the interaction point. The horizontal aperture is 60 mm and the vertical aperture is 30 mm. This large horizontal aperture is necessary in order to prevent any synchrotron radiation from BEND from hitting the beryllium beam pipe.

Figure 3 shows an arrangement of horizontal masks. The aperture of is chosen so that photons emitted by the beam particles within $10\sigma_x$ of the beam size at

BEND, QCD, QC3H, BNDL, and QC2L do not hit the beryllium part of the beam pipe wall and mask-A directly. Photons emitted outside of $4.6\sigma_x$ at QC4H can hit mask-A if they are not intercepted; they are, however, obstructed by the beam pipe wall near QC3H. Figure 4 shows the shadowed region caused by mask-A. Photons scattered along the beam pipe wall within this region do not hit the beryllium beam pipe directly. The number of photons which can reach the beryllium beam pipe by scattering outside this region are reduced by adding mask-C. This mask must be placed inside the shadowed region in order to avoid being hit by $10\sigma_x$ photons. Mask-C and a movable mask placed either outside of QC4H or QC2L stop most of the photons emitted at the far away magnets not shown in Fig. 1. Since the vertical beam size is much smaller, only a small mask at mask-A is necessary to stop back-scattered photons.

In this proposed design, the beryllium beam pipe is shielded against both direct and once-scattered photons emitted within 10σ of the beam size at all magnets shown in Fig. 1. It is estimated that the number of photons entering the detector is less than 10^{-3} per beam crossing, which we think is negligible. If the beam size happens to be much larger than the design value, photons emitted at QC3H and backscattered at mask-A will start to reach the detector. For example, if the beam emittance is four times larger, photons from the beam particles above $8.5\sigma_x$ will hit mask-A directly. We believe this is still safe.

3. Spent Electrons

Background contributions from spent electrons were studied using the DECAY TURTLE code, which includes the bremsstrahlung process. Off-momentum particles in an 8-GeV beam produced upstream of QC3H are swept out by QC3H. Their horizontal distribution at the z -position corresponding to mask-B is shown in Fig. 5 (1). Particles at larger horizontal distance have a smaller momentum, and particles below 5 GeV are cut out. Particles passing through mask-B clear mask-A, as can be seen in Fig. 5 (2), where the horizontal distribution at the z -position of mask-A is shown. Leakage of showers generated at mask-B can be stopped with a combination of mask-A and another shield which covers the outside of the beam pipe at mask-B. Without mask-B, off-momentum particles hit mask-A. Since mask-A is very close to the detector, it is difficult to stop a leaking shower from it. It may be necessary to distinguish true triggers from those originating from the masks by requiring a stringent z -coordinate cut. For a low-energy beam, BNDL plays a similar role as does QC3H in the high-energy beam.

Off-momentum particles produced inside QC3H or BNDL are swept out at BEND and hit both mask-A and the beryllium beam pipe. Their energy is about 2 GeV for both beams. If the vacuum pressure in the interaction region is 10^{-9} torr, the rates of direct hits are 0.8 and 8 kHz for an 8 GeV, 0.26 A beam and a 3.5 GeV, 0.55 A beam, respectively. Based on experience at TRISTAN, we think

that these rates are manageable.

During injection, the beam loss might be significantly larger. If they hit the masks near the interaction point, a problem of radiation damage might occur. This can be prevented by placing another mask far away from the interaction point and set its jaws closer to the beam compared with that of the IR masks. Oide's calculation¹ shows that this scheme is possible.

In conclusion, it is possible to make a good condition for beam background by using many masks and a beryllium beam pipe with an optimized radius.

Reference

- 1) K. Oide, Talk presented at International Workshop on Accelerators for Asymmetric B-Factories, October 1990, Tsukuba, Japan.

Figure Captions

Fig. 1 Layout of the interaction region.

Fig. 2 Cross section of the beryllium beam pipe.

Fig. 3 Arrangement of horizontal masks.

Fig. 4 Region shadowed by mask-A (hatched area).

Fig. 5 Number of particles passing through the IR beam pipe.

Figure 1: Layout of the interaction region.

Figure 2: Cross section of the beryllium beam pipe.

Figure 3: Arrangement of horizontal masks.

Figure 4: Region shadowed by mask-A (hatched area).

Figure 5: Number of particles passing through the IR beam pipe.

Heating at the Interaction Region

K. Akai

1. Introduction

Masks will be located at the interaction region (IR) in order to reduce any synchrotron-radiation background in the detector. When bunches pass the masks, wake fields are generated and a part of beam power is extracted as the higher-order mode (HOM) rf power. Some part of the HOM rf power will propagate out from the IR, but other part will be absorbed at the Be pipe in the IR, where effective cooling is quite difficult. In addition to the HOMs generated at the masks, ohmic loss at the Be pipe and HOMs propagating from outside the IR also heat the Be pipe. In this report we estimate the power loss at the Be pipe in order to design the masking system at the IR.

The present design of the IR is shown in Fig. 1. In the IR we have a Be pipe with a race-track shape and a length of 20 cm around the colliding point. Detailed design of the IR will be described elsewhere.^{1),2)} Since beam pipes including the masks outside the Be pipe can be cooled effectively, we consider here only heating at the Be pipe.

2. HOMs Generated at Masks

It is difficult to estimate the HOM loss accurately, since the IR forms a rather complicated structure. As an approximation of the power loss at the Be pipe, we examined cylindrically symmetric structures. We tried two independent methods: one was by using TBCI³⁾ and the other by using URMEL.⁴⁾ After the HOM loss was estimated with the cylindrically symmetric structure, we took account of difference between the cylindrical model and the actual structure.

A calculation with the TBCI gives the wake potential, $V(t)$, and a loss factor, k , which gives the total energy lost by a bunch of unit charge passing through the IR. However, only a part of the power lost by the bunch is absorbed at the Be pipe. A ratio of the power dissipation at the Be pipe to the total loss depends on the shape of the IR. If there is no cavity-like structure including the Be pipe region, most of the energy loss of the bunch is expected to propagate down the beam pipe from the IR. The method to estimate the ratio by using the TBCI will be presented at first. If the Be pipe and masks form a cavity, on the other hand, a large amount of energy can be stored as resonant modes. In this case we use URMEL in order to determine the resonant modes, as will be discussed afterwards.

We suppose that the bunch is Gaussian with a r.m.s. bunch length, σ_z . The power spectrum of the radiated HOM in the frequency domain is obtained by

Fourier-transforming the wake potential calculated from TBCI. Then spectrum of the deposited power is

$$P(\omega)d\omega = V(\omega)I^*(\omega)d\omega, \quad (1)$$

where

$$V(\omega) = \frac{1}{\sqrt{2\pi}} \int V(t)e^{-j\omega t}dt \quad (2)$$

and

$$I(\omega) = \frac{1}{\sqrt{2\pi}} \int I(t)e^{-j\omega t}dt. \quad (3)$$

Wake fields well above the cut-off frequency of the Be pipe will propagate down the beam pipe. If we consider the propagation of a TM_{0m} mode wave in a circular waveguide, the group velocity, V_g , is represented as

$$V_g = c\sqrt{1 - \left(\frac{j_{0m}c}{r_b\omega}\right)^2}, \quad (4)$$

where r_b , ω , j_{0m} and c are the radius of the Be pipe, the angular frequency, the m -th zero point of the zero-th Bessel function and the velocity of light.

The wall loss per unit length, P , is

$$P = P_0e^{-\alpha z}, \quad (5)$$

where α is

$$\alpha = \sqrt{\frac{2\omega}{\mu\sigma}} \times \frac{1}{r_b V_g}, \quad (6)$$

σ is the conductivity and $\mu = 4\pi \times 10^{-7}(\text{Ns/m})$. The ratio of the power absorbed at the Be pipe to the total radiated power is

$$R = \frac{\int_0^L P_0e^{-\alpha z}dz}{\int_0^\infty P_0e^{-\alpha z}dz} = 1 - e^{-\alpha L}, \quad (7)$$

where L is the length of the Be pipe. The power dissipated at the Be pipe is represented as

$$W_{Be} = 2 \int_0^\infty R(\omega)V(\omega)I^*(\omega)d\omega. \quad (8)$$

We estimate $R(\omega)$ in the case of the KEK B-Factory assuming the propagation of a TM_{01} mode wave. V_g/c and α for the TM_{01} wave as functions of frequency are shown in Fig. 2, taking $r_b=27$ mm and $\sigma=3.57 \times 10^7/\Omega\text{m}$. The cut-off frequency is

4.25 GHz. In the frequency range from 4.7 to 40 GHz, $1/\alpha$ is of the order of 100 m and R is only 0.2%. As for in a frequency range of higher than 40 GHz, $1/\alpha$ reduces in proportion to $1/\sqrt{\omega}$ and R becomes larger. However, in this frequency range the power lost by a bunch is negligibly small, assuming that the bunch length, σ_z , is 5 mm. Wake fields near the cut-off frequency, on the other hand, have a low group velocity and can not propagate very far by the time the next bunch arrives at the IR. Thus not a small part of the power will be absorbed at the Be pipe. We assume here that all of the power below 4.7 GHz is absorbed at the Be pipe.

In case a Be pipe and masks form a cavity, we must take the resonant modes into account. A calculation with the URMEL gives the frequency and R/Q for each resonant mode. The stored energy in the Be pipe region is calculated as

$$W_{Be} = \sum \frac{\omega}{2} \left(\frac{R}{Q} \right), \quad (9)$$

where all modes below the cut-off frequency are summed.

In both cases, the total power absorbed at the Be pipe is

$$P_{Be} = W_{Be} \frac{(I_{e+}^2 + I_{e-}^2)}{f_{rev} \times N_b}, \quad (10)$$

where I_{e+} , I_{e-} , f_{rev} and N_b are the beam current of positrons, that of electrons, the revolution frequency and the number of bunches, respectively.

Although the final design of the masks has not yet been decided, two examples of masks are examined here. In the following calculation, we consider the 1/5 bucket filling option at step 1 with the luminosity of $2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$, taking $I_{e+}=0.52$ A, $I_{e-}=0.22$ A, $f_{rev}=235$ kHz and $N_b=432$.

(A) Two horizontal masks

One example of the masking system is shown in Fig. 3a. It comprises two horizontal masks, one of which is attached at the inner side of the ring to reduce the radiation background from HER; the other is attached at the outer side to reduce that from LER. These masks are located next to the Be pipe.

The IR region including the masks is approximated as being a cylindrically symmetric structure. Two horizontal masks are brought together in one cylindrical mask. Since the beam pipes near the Be pipe are larger than the Be pipe, we consider that no cavity structure exists including the Be pipe region. The input data used for TBCI calculation is shown in Fig. 3b.

TBCI calculation gives $k = 0.12$ V/pC. The total power lost by the beam is 377 W. The power spectrum in the frequency domain shows that 90% of the total power is in the frequency range from 4.7 to 40 GHz and that the power lost below 4.7 GHz is 44 W.

We next consider the difference between the cylindrical model and the actual structure. We calculated a cylindrically symmetric structure with a round mask.

Actually, each mask is located at only one side of the beam pipe in the case of this example. We estimate the ratio of the generated HOMs in the actual structure to that in the cylindrical model as follows. If we consider that it is equal to the ratio of areas, it is 14%. If we consider that it is equal to the ratio of angles seen from the beam axis, on the other hand, it is 38%. Combining these two viewpoints, we assume that the ratio is 30%. Furthermore, the generated wake field propagates in both directions, toward the Be pipe and in the opposite direction as well. We exclude half of them from the estimation of wall loss at the Be pipe.

Finally the estimated wall loss at the Be pipe is

$$(377 \times 0.9 \times 0.002 + 44) \times 0.3 \times 1/2 = 6.7(W).$$

(B) Two race-track shaped masks

Another example of the masking system is shown in Fig. 4a. This comprises two race-track shaped masks attached around the beam pipe. The input data used for TBCI calculation is shown in Fig. 4b. Similar to the case of the two horizontal masks described above, the spectrum of the power lost is calculated using TBCI. The power below 4.7 GHz is 62 W.

In this case there may exist trapped modes in the Be pipe region, since it is surrounded by two masks, which form a cavity. The frequency and R/Q of the resonant modes were calculated using URMEL. Table 1 shows the main resonant modes below the cut-off frequency. The sum of the loss factor of these three modes is $\sum k = 2 \times 10^{10} \text{ V/C}$. The power extracted from the beam through these modes is 63 W, which is in good agreement with the result from TBCI calculation.

Table 1. Main resonances of the IR with two race-track shaped masks.

modes	freq.(MHz)	R/Q(ohm)	k (V/C)
TM010	4289	0.007	9.4×10^7
TM011	4408	0.60	8.3×10^9
TM012	4607	0.81	1.17×10^{10}

3. Ohmic Loss

The ohmic loss power per unit area is represented as

$$P = W_o \times \frac{(I_{e+}^2 + I_{e-}^2)}{f_{rev} \times N_b}, \quad (11)$$

where W_o is the ohmic loss energy caused by one bunch with a total charge of 1 coulomb. If we assume a Gaussian bunch, W_o is

$$W_o = 3.92 \times 10^{-6} \times \frac{1}{r_b^2} \times \left(\frac{c}{\sigma_z}\right)^{\frac{3}{2}} \times \sqrt{\frac{1}{\sigma}}. \quad (12)$$

Taking $r_b=27$ mm, $\sigma_z=5$ mm and $\sigma=3.57 \times 10^7/\Omega\text{m}$, and multiplying the power by the area of the Be pipe, the ohmic loss power absorbed at the Be pipe is estimated to be 1.4 W.

4. HOM from the Ring

HOM rf is generated around the ring. Some part of them propagates toward the IR and is absorbed at the Be pipe. It is not easy to estimate the total impedance of the ring. We thus use the total impedance measured in the TRISTAN Main Ring and scale it down to the KEK B-factory according to the ratio of the circumference. The loss factor of the TRISTAN Main Ring was measured to be $k=1000$ V/pC with the bunch length of 5 mm⁵⁾. Then, the loss factor of the KEK B-factory is estimated to be 424 V/pC and the total power lost by the beam around the ring is 1.3 MW in the case of step 1. Assuming the power is dissipated uniformly around the ring, the additional heating at the Be pipe is 200 W. Actually, a part of them whose frequency is below the cut-off frequency of the Be pipe does not propagate to it and should be excluded from the estimation of the heating at the Be pipe.

Summary

We estimated the power loss at the Be pipe in the IR in the case of 1/5 bucket filling option with the luminosity of $2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$. If we use two horizontal masks, the power dissipation at the Be pipe caused by HOMs generated at the masks and by ohmic loss amounts to about 8 W, assuming that there is no cavity structure at the IR. In the case of two race-track shaped masks around the beam pipe, about 65 W will be absorbed at the Be pipe. In addition, HOMs propagating from outside the IR is estimated to be less than 200 W. If this additional power loss is undesirable, some absorbers will be needed.

Acknowledgements

The author would like to thank Profs. K. Takata, Y. Yamazaki and K. Satoh for useful discussions.

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Figure Captions

Fig. 1 The present design of the interaction region.

Fig. 2 The group velocity and the attenuation constant of TM01 mode wave.

Fig. 3 (a) A masking system with two horizontal masks and (b) the input data for TBCI.

Fig. 4 (a) A masking system with two race-track shaped masks and (b) the input data for TBCI and URMEL.

Figure 1: The present design of the interaction region.

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Figure 3: (a) A masking system with two horizontal masks.
(b) The input data for TBCI.

Figure 4: (a) A masking system with two race-track shaped masks.
(b) The input data for TBCI and URMEL.

Damped RF Cavity

M. Suetake, K. Akai, T. Higo, K. Takata and Y. Yamazaki

Abstract

In order to obtain the designed luminosity for the KEK B-Factor, the ring should be operated at a high current in a multi-bunch operation scheme. In this case, higher-order modes excited in a cavity by preceding bunches are likely to cause coupled-bunch instability. In order to suppress this instability, we have investigated and optimized a cavity whose Q values are sufficiently reduced for the higher-order modes. The optimized cavity has sufficient performance for a 432-bunch scheme (first step) and no feedback system is necessary.

In this paper we first show the requirements of the Q values for the higher-order modes; we then describe the optimization of a damped cavity using a 3-dimensional code called MAFIA to try to produce Q values on the order of 20. Lastly, we show the profile of a prototype damped cavity (which is now under construction) and show the performance of the accelerating mode.

1. Introduction

The high-power klystron stations which are now in operation for the TRISTAN RF system will be used for the KEK B-Factor. Since no significant modification will be necessary on these power stations, no discussion is presented concerning the power stations. On the other hand, new accelerating cavities should be developed in order to meet requirements of the B-Factor by the following reasons.

A high luminosity B-factory requires extremely high threshold currents for all kinds of instabilities. In particular, the threshold current of the coupled-bunch instability should be by orders of magnitude higher than that of a ring using conventional cavities. In other words, impedances of higher-order modes of the cavities should be reduced by orders of magnitude, as is discussed in the next section. For this purpose we have investigated a damped cavity proposed by Palmer[1][2], and optimized its structure while taking into account feasibility under high-power, high-beam-loading operation. The structure thus optimized is presented in Sec. 3. Using the optimized damped cavities we propose an RF system in Sec. 4.

2. Requirements for the Q -values of the Higher-Order Modes

The higher-order modes characterized by their high impedances are TM₁₁₀-like, TM₁₁₁-like and TM₀₁₁-like modes. We thus concentrate in this paper on these three modes. The Q values of these higher-order modes should be reduced, as shown in Table 1[3], in order to realize the operation of the first step or the second

Table 1: Requirement of cavities in LER.

Mode Name	Q_{ext}	
	step 1 (432 bunches)	step 2 (2160 bunches)
TM110-0	< 50	< 10
TM110- π	< 56	< 13
TM111-0	< 35	< 9
TM111- π	< 24	< 6
TM011-0	< 70	< 17
TM011- π	< 30	< 8

The head-tail damping is dominant for the damping of the transverse oscillation, while the longitudinal radiation damping is dominant for the damping of the longitudinal oscillation.

shown in Table 1[3], in order to realize the operation of the first step or the second step of the KEK B-Factory. Only the parameters for the 3.5-GeV low-energy ring (LER) are listed in this table, since the requirements for the LER are 2.3 times as severe as those for the 8-GeV high-energy ring (HER), owing to their energy difference. In order to estimate these required Q -values we used the following values. First, we used the R/Q of the higher-order modes of the optimized cavity (see Sec. 3). Second, the number of cells necessary for the rings was estimated from the parameters of the optimized damped cavity (see Sec.4). Third, we took into account head-tail damping time for the transverse oscillation, as well as the longitudinal radiation damping time for the longitudinal oscillation.

It can be seen from the table that the required Q -values are extremely lower than those of the conventional accelerating cavities. These low Q values have never been realized in any power-tested cavities.

3. Optimization of the Damped Cavity

In order to meet the above requirements, we investigated and optimized a damped cavity. The damped cavity proposed by Palmer for linear colliders is characterized by radial slots and irises coupled to the waveguides. The radial slots on the wall between cells intercept the wall current of the TM11-like mode and work as antennas for the waveguides. The cutoff frequency of the waveguides must be sufficiently lower than the frequencies of the higher-order modes in order to guide the higher-order modes, while sufficiently higher than the fundamental accelerating frequency in order to confine the accelerating mode. Instead of the full-slot cavity originally proposed by Palmer, we introduced a partial-slot cavity (Fig. 1). The advantages of this type cavity can be summarized as follows:

cavity, since there are no sharp edges on the beam aperture of the disk, where a strong accelerating field exists.

2. No slot modes exist in the partial slot case. The slot modes in the full-slot cavity may be coupled to the beam; however, the mode cannot be damped because those frequencies are below the accelerating mode.
3. The partial-slot cavity is mechanically strong, as can be seen from Fig. 1.

Because of the large beam loading and the limit of the power through an input coupler (as mentioned later), we chose the minimum number of cells, two for a damped cavity. Furthermore, for a 2-cell cavity, one can have a merit of sufficiently low impedance of other fundamental mode i.e. 0-mode, because we can make 0-mode orthogonal to π -mode. On the contrary, for a more than 3-cell cavity, we cannot make, for example, $\pi/2$ -mode orthogonal to π mode.

In order to increase the shunt impedance of the accelerating mode, a nose cone was attached to the damped cavity. Under these constraints we attempted to realize a damped cavity with Q values of the order of 20 for the higher-order modes.

The calculation of the external Q value is based upon the tuning-curve characteristics described in the text of Slater[4][5]:

$$\frac{dL}{d\lambda_g} = \frac{2n+1}{4} + \frac{Q_{ext} \cdot v_g}{\pi v_p}$$

where λ_g , v_g and v_p are the wavelength, group velocity and phase velocity in the waveguide, respectively, and n is an integer. For a cavity coupled with four waveguides which are shorted at a distance of L from the coupling irises, we calculated the resonant frequency by the three-dimensional code, MAFIA[6]. The optimization was carried out by varying the slot width, slot length, waveguide size and wall thickness between cells.

The thus-optimized structure is shown in Fig. 2. The external Q values of the higher-order modes are listed in Table 2. By comparing Table 1 with Table 2, it can be seen that the Q values satisfy the requirements for the 432-bunch scheme (the first step), except for the TM011 0-mode.

The TM011 0-mode is not coupled to the waveguide for the following reason. As can be seen from the electric field pattern of the TM011-0 mode shown in Fig. 3, the mode is coupled to the TM11 mode in the waveguide. Since the frequency of the TM011 0-mode is just below the cutoff frequency of the TM11 waveguide mode, the TM011 mode cannot be damped through the waveguide. (The cutoff frequency of the TM11 mode is 1.4 times as high as that of the TE10 mode, through which other higher-order modes are coupled to the waveguide.) In general, although it is possible to lower the cutoff frequency by enlarging the size of the waveguide, it is impossible any more for the damped cavity, as can be seen from Fig. 2. Therefore, we must

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

Mode-id	Q_{ext}	R/Q
TM110-0	< 10.0	322 Ω/m
TM110- π	29.9	281 Ω/m
TM111-0	20.1	1191 Ω/m
TM111- π	12.0	1862 Ω/m
TE112-0	223	63.6 Ω/m
TM011-0	<i>uncoupled</i>	9.1 Ω
TM011- π	10.6	25.5 Ω
TM012-0	38.2	8.0 Ω
TM012- π	<10.0	6.6 Ω

impossible any more for the damped cavity, as can be seen from Fig. 2. Therefore, we must develop other methods in order to couple the TM011 0-mode. Two ideas are shown in Fig. 4. The first method is to use a cone-type dummy load, which couples the electric field directly. The second method is to use a coaxial-type dummy load.

For the 2160-bunch scheme (the second step) the obtained Q-values are still by a factor of two higher than that required. Thus, some damping system is necessary for the second step operation[7].

4. Accelerating Cavity System

The characteristics of the fundamental accelerating mode of the damped cavity are listed in Table 3. Fundamental mode coupling of 3.0% is large enough for the cell-to-cell propagation of power in the two-cell cavity. It is noted that the impedance of the 0-mode, which is harmful to the beam stability, is sufficiently small, as shown in Table 3.

Using these parameters we have designed the accelerating cavity system shown in Table 4. In addition to the given parameters of the total cavity voltage and beam loading, we have imposed two constraints: that the wall loss in a cell be less than 30 kW, and that the power through an input coupler be less than 200 kW. One may argue that these constraints are too conservative. Increasing these two parameters, one should have saved the number of cells in order to reduce the total impedances of the higher-order modes. However, it should be noted that a damped cavity is difficult to cool, being equipped with the large slots in the wall between cells and large open area for the damping waveguide. These cuttings tend to increase the local current density, while making it difficult to realize a good water-cooling. Also,

Table 3: The performance of the damped cavity for the fundamental mode.

Frequency of fundamental mode	f_0	508.58 MHz
Intrinsic quality factor	Q_0	27,500
Impedance	R	18.3 M Ω /m
Fundamental mode coupling		3.0%
Ratio of the 0 mode impedance to that of the π mode impedance		0.4%

Table 4: Damped cavity parameters in LER and in HER.

	HER (8.0 GeV)	LER (3.5 GeV)
Shunt impedance	18.3 M Ω /m	
Power loss	30 kW/cell	28 kW/cell
Voltage	0.4 MV/cell	0.39 MV/cell
Total # of cells	88	40
# of klystrons	11	5
Total cavity voltage	35.6 MV	15.6 MV
Beam loading	51 kW/cell	60 kW/cell
Coupler power	162 kW/coupler	176 kW/coupler
Length for cavity area	44 m	20 m

a power per input of 200 kW is necessary in order to guarantee stable operation of the RF system. Taking these factors into account, together with the experience of the Photon Factory and TRISTAN, we chose the above-mentioned parameters being reasonable.

5. Conclusions

We have investigated and optimized a damped cavity whose Q values are sufficiently reduced for the higher-order modes. It was concluded that without any feedback damper system, an optimized damped cavity could be used for a 432-bunch scheme (the first step). In order to confirm the reduction of the Q values and high power operation, a prototype damped cavity is being constructed.

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Figure captions

- Fig. 1 Two types of the slots on the disk: (a) full-slot cavity (Palmer type) and (b) partial-slot cavity.
- Fig. 2 Schematic drawing of the two-cell damped cavity of the B-Factory.
- Fig. 3 Electric field in the damped cavity for the TM₀₁₁ 0-mode.
- Fig. 4 (a) Cone type dummy load and (b) coaxial type dummy load to catch the TM₀₁₁ 0-mode field.

(a) full slot type

(b) partial slot type

Figure 1: Two types of the slots on the disk: (a) full-slot cavity (Palmer type) and (b) partial-slot cavity.

Electric field of TM011 0-mode

Figure 3: Electric field in the damped cavity for the TM011 0-mode.

Figure 4: (a) Cone type dummy load and (b) coaxial type dummy load to catch the TM₀₁₁ 0-mode field.

Coupled Bunch Instabilities

E. Kikutani

We present our estimation for the strengths of coupled bunch instabilities in the rings at the KEK B-Factory as well as our strategy to overcome them. The actual design of the damper system is given in the paper#11 of this report.

1. General Remark

In B-factories, where many bunches are stored in a ring, one of the problems to be solved is how to overcome the difficulties due to coupled bunch instabilities. Because the main source of these instabilities is higher-order modes of accelerating cavities, we must devise methods to decrease the coupling impedances of these higher-order modes. For this purpose, it is effective to attach waveguides to a cavity. Through these waveguides the higher-order modes can propagate out and be damped by some resistive material.

There may be two ways for attaching the waveguides. One is to use one part of a beam pipe as the waveguide (type *A*). The other choice is to use a cavity to which extra waveguides are attached at the side of cavity body (type *B*).

Figure 1: Types of damped cavities.

Both choices have advantages and disadvantages; which one is finally chosen depends on the results of presently ongoing R&D. At KEK, we made a policy to cope with this problem as follows:

- to use type *B* (KEK type 2-cell damped cavity) to decrease quality factors of higher-order modes as low as possible, and
- to use damper systems to cure any still-existing instability modes.

2. Higher-Order Modes of the KEK Damped Cavity

As already explained in paper#9 of this report, optimization of the cavity shape is done using the computer code, MAFIA. Parameters of the main higher-order modes are obtained as listed in Table 1¹.

Table 1: Higher-order modes of the KEK damped cavity.

mode-ID	freq.(MHz)	Q_{ext}	$R/Q(\Omega)$
<i>Longitudinal modes</i>			
TM011-0	952	<i>uncoupled</i>	9.1
TM011- π	894	10.6	25.5
TM012-0	1191	38.2	8.0
TM012- π	1016	< 10.0	6.6
<i>Transverse modes</i>			
mode-ID	freq.(MHz)	Q_{ext}	$R/Q(\Omega/m)$
TM110-0	989	< 10.0	322
TM110- π	827	29.9	281
TM111-0	1130	20.1	1191
TM111- π	1088	12.0	1862
TE112-0	1200	223	63.6

3. Expected Growth Times for Stationary States

In the KEK B-factory, the target luminosity will be achieved in two steps. In the first step, where every fifth RF bucket is filled with a bunch (1/5 filling option), the number of bunches is about 400 and the bunch spacing is 3 m. In the the second step, where the peak luminosity will be $1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$, all the RF buckets are to be filled with beams; the bunch spacing is only 60 cm or 2 nsec (all RF bucket filling option).

For the both options, we estimated the growth times of the instabilities using a computer code, ZAP¹⁾. For the input parameters of ZAP we used the impedances listed in the above table and the machine parameters given in Table 2.

The obtained expected growth times in milli-second are listed in Table 3. Also the radiation damping times are listed as references.

From these results, we find that:

¹In this table there is a mode uncoupled to waveguides. In actual design a coaxial structure in the waveguides will be used and Q-factor will be decreased.

Table 2: Machine parameters of the KEK B-Factory.

	HER (step I/II)	LER (step I/II)
Energy (GeV)	8.0	3.5
RF freq. (MHz)	508.6	
Harmonic number	2160	
Number of bunches	432/2160	
Total current (A)	0.22/1.1	0.52/2.6
Required acc. volt. (MV)	35	15
Number of cavity cells	88	40
Momentum compaction	1.8×10^{-3}	1.5×10^{-3}
Momentum spread	7.2×10^{-4}	7.9×10^{-4}
Bunch length (cm)	0.5	

Table 3: Expected growth time of the instabilities in msec.

mode-ID	HER (step I/II)		LER (step I/II)	
<i>Longitudinal modes</i>				
<i>rad. damp. time</i>	8		16	
TM011- π	245	19.2	108	8.48
TM012-0	72.0	12.4	31.8	5.47
TM012- π	1532	163	686	73
<i>Transverse modes</i>				
<i>rad. damp. time</i>	16		32	
TM110-0	2.22×10^7	824	9.07×10^6	336
TM110- π	136.	21.5	55.5	8.76
TM111-0	89.9	7.65	36.7	3.12
TM111- π	127	8.89	51.8	3.63
TE112-0	63.8	12.7	26.1	5.18

Table 4: Types of damper systems.

<i>damper type</i>	<i>method</i>	<i>hardware</i>	
passive	Landau damp.	long.	higher-harmonic cavities
		trans.	non-linear magnets
	decoupling	long.	side band cavities
		trans.	RF-Q's/AC Q-mag.
active	bunch by bunch		
	mode-identified		(mode analyzer)

- if the quality factors of the higher-order modes are decreased to the calculated values, the growth time is longer than the radiation damping times in the 1/5 filling option, and that
- the growth times are shorter in LER than in HER, although the radiation damping time is longer in LER.

4. Damper Systems

From the conclusions in the previous section, we must prepare damper systems in order to cure the coupled bunch instabilities, at least for the all-bucket-filling option. For the 1/5 filling option, if the Q-factors of the higher-order modes are not sufficiently decreased due to various hardware problems, we may require damper systems.

Some types of damper systems are summarized in the Table 4. We must choose a relevant system among these damper types. We made a strategy for constructing the dampers for the first step, as follows. For the transverse case, we will use a bunch-to-bunch feedback system². For the longitudinal modes, on the other hand, we will use a decoupling method in which longitudinal tunes (ν_s) are varied bunch by bunch.

In the second step, where the growth times of the instabilities due to some higher-order modes are very short, the concept of a damper system is not quite different from that in the first step. Regarding longitudinal direction, the decoupling method will also be effective in the second step. For the transverse dampers, more power will be necessary for the feedback system. Studies with a multi-particle tracking program shows that the Landau damping effect will help the feedback system and the oscillation of bunches will be safely damped as explained in the paper#11 in this report.

²Recently we started to check feasibility to use AC-operated quadrupole magnets. If those magnets are useful, we may choose the decoupling method for a transverse damper.

Summary

In order to suppress coupled-bunch instabilities, we will use the damped cavities, a prototype of that is now under construction. As explained in the paper#9 of this report, the quality factors of the higher-order modes will be very low according to the calculation with MAFIA. Based on the calculation with ZAP, no damper system is required for the first step of the KEK B-Factor, if these quality factors are realized by the actual cavities. Still, we plan to construct damper systems, to be on the safe side. Development of these systems must be very fruitful for preparing more powerful feedback systems for the second step. Some types may be usable for the damper systems; we will use a method of making bunch-by-bunch synchrotron tune spread for the longitudinal direction and active feedback systems for the transverse directions.

Reference

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Cure of Coupled-Bunch Instabilities

K. Hanaoka

1. Introduction

One of the greatest problems at the KEK B-Factory is how to cure coupled-bunch instabilities. Two types of dampers can be used to cure them: one is an active damper and the other is a passive one. We will use an active bunch-by-bunch feedback system for the transverse modes; for the longitudinal modes, however, we will use a passive damping system by which synchrotron tunes (ν_s) are varied bunch to bunch.

2. Cure of Coupled-Bunch Instabilities for the One-Fifth Filling Scheme

Transverse feedback

We will use two sets of deflectors, each of which comprises four striplines of 1.3 m in length; the gaps between adjacent striplines are to be 10 cm. The damping-rate, α , of a feedback system for transverse directions is determined by

$$\alpha = \frac{Le}{T_{rev}E} \sqrt{\frac{\beta}{\varepsilon} \frac{\sqrt{8Z_0P}}{g}}, \quad (1)$$

where L is the length of the stripline, e the charge of an electron, T_{rev} the revolution period of the beam, E the energy of the beam, β the beta function at the stripline, ε the coherent emittance of the injection error, Z_0 the impedance of the stripline, P the peak power of the driver amplifier, and g the gap between striplines. The damping time is $1/\alpha$. Maximum power is required during injection, at which the emittance is 1.2×10^{-5} m. If we drive each stripline with 1kW power, we can expect damping times of 0.85 msec in LER and 2.0 msec in HER. Table 1 lists the parameters of the transverse feedback system and Fig. 1 shows a schematic diagram of the feedback system.

Longitudinal decoupling

To damp coherent dipole oscillations in the longitudinal direction, we will make a bunch-to-bunch synchrotron tune spread by installing side-band cavities. The effect of the tune spread has been estimated by a tracking program. In this program a bunch, which is regarded as being a macro particle, is tracked through an impedance source, an RF acceleration field and an arc section. When the bunch passes through the impedance source, it produces wake fields and at the same time is kicked by the wake fields which have been made by previous bunches.

After trial and error, the frequency of the side-band cavities was determined to be $f_{rf} + 40f_0$, where f_{rf} is the RF frequency and f_0 is the revolution frequency. The

Table 1: Parameters of the transverse feedback system in the one-fifth filling scheme.

beam energy	3.5 GeV	8 GeV
Revolution time	4.2 μ sec	4.2 μ sec
Beta function	10 m	10 m
Bunch spacing	10 nsec	10 nsec
Feedback bandwidth	10 kHz~ 220 MHz	10 kHz~ 220 MHz
Length of stripline	1.3 m	1.3 m
Stripline impedance	50 ohm	50 ohm
Power for deflector	1kW $\times$ 4	1kW $\times$ 4
Number of deflectors	2	2
Number of driver amp.	8	8
Damping time	0.85 msec	1.95 msec

Figure 1: Schematic diagram of the feedback system for the one-fifth filling scheme.

Figure 2: Minimum required tune spread to damp the longitudinal instability as a function of the HOM impedance.

minimum tune spread ($\delta\nu_s$) required to damp longitudinal oscillations is represented by the dotted line in Fig. 2 for LER, where instabilities are more severe than in HER.

Effect of missing bucket train

We also studied the effect of missing buckets by the use of the tracking code. Figure 3 shows the growth time of transverse coupled-bunch instabilities as a function of a missing ratio; the missing ratio is defined as being the ratio between the number of missing buckets in a train and the total number buckets. In the KEK B-Factory, where missing ratio is small, a missing bucket train does not significantly affect the growth rate.

Transient behavior of bunches just after an injection

The behavior of bunches just after an injection was also studied using the track-

Figure 3: Growth time of transverse instabilities as a function of the missing ratio.

Figure 4: Variation of the oscillation amplitude of bunches after the last injection. The horizontal axis is the number of turns after an injection; the vertical axis is the oscillation amplitude. *A*, *B* and *C* represent the amplitude for a bunch already in the ring, for the leading bunch of the newly injected bunch train and for the middle bunch of the injected bunch train. The dashed line indicates the largest amplitude among all of the bunches.

ing procedure. We first discuss the transverse case. In order to estimate the transient behavior of bunches for the worst case, we assumed that the growth rate of the instability is 90% of the damping rate. Figure 4 shows the behavior of bunches after the last injection to LER: all of the buckets except for the last 20 buckets had already been filled with the beam and by this injection the last 20 could be filled. In the figure, trace *A* represents the behavior of a bunch which was already in the ring; traces *B* and *C* represent that of newly injected bunches. Because *B* is for the leading bunch, its oscillation is damped very quickly. Since bunch *C* is in the middle of the injected bunch train, its oscillation is damped slowly due to a cumulative effect of the wake fields produced by preceding bunches. The dashed line in the figure indicates the largest amplitude among all of the bunches. We can conclude that in the KEK B-Factory if we can make the growth rate of transverse coupled-bunch instabilities shorter than the damping rate, the transient behavior will not lead to beam losses.

For the longitudinal case, if a synchrotron tune spread is introduced to damp the instability, a larger tune spread becomes necessary during injection. The solid line in Fig. 2 indicates the necessary tune spread as a function of the HOM impedance for the transient case.

3. Cure of the Coupled-Bunch Instabilities for the Filling Scheme Involving All of the Buckets

Feedback system in the transverse direction and the effect of Landau damping

To damp the coupled-bunch instabilities we will also use a bunch-by-bunch feed-

Figure 5: Equilibrium (dashed line) and oscillation (solid line) emittance.

back system for the transverse modes. In the filling scheme for all of the buckets the number of bunches is five times as large as that in one-fifth filling scheme and the bunch spacing is reduced to 60 cm from 3 m; the growth time of coupled-bunch instabilities becomes shorter owing to an increase in the total current and a decrease in the bunch spacing. It may be difficult to design a bunch-by-bunch feedback system which can effectively damp the coupled-bunch instabilities in the transverse direction; we can take into account, however, the effect of Landau damping which produces strong damping in order to alleviate the burden of the feedback system. Due to the nonlinearity of the magnets, each particle in a bunch oscillates with a different amplitude and has a different tune; this leads to a strong damping called Landau damping. The effect of Landau damping was estimated by a tracking program. In this program a bunch, which is regarded as a group of particles, is tracked through an impedance source and a one-turn transfer function which incorporates nonlinearity due to sextupole magnets. We also take radiation damping into account. Figure 5 summarizes the effect of Landau damping of the coupled bunch instabilities. In this figure the dotted line represents the equilibrium emittance of the bunch established between blow-up due to coupled-bunch instabilities and Landau damping. The solid line in the figure shows the oscillation emittance of the bunch center in terms of emittance. The horizontal axis represents the strength of the impedance source.

We can assume the above-mentioned oscillation emittance as an input to formula (1) which is used to calculate the necessary power required for the feedback system in the scheme for filling all of the buckets; with a sufficient margin, we may take ϵ of 0.5×10^{-6} m. Table 2 summarizes the parameters of the feedback system, which has ten sets of deflectors comprising four striplines which are 10 cm long with the gap of 10 cm. If we feed 1 kW of power to each stripline, we can obtain a damping time of 0.90 msec in LER and 2.1 msec in HER. Figure 6 is a schematic diagram of the feedback system.

Table 2: Parameters of the transverse feedback system in the whole-bucket filling scheme.

beam energy	3.5 GeV	8 GeV
Revolution time	4.2 μ sec	4.2 μ sec
Beta function	10 m	10 m
Bunch spacing	2 nsec	2 nsec
Feedback bandwidth	10 kHz~1 GHz	10 kHz~1 GHz
Length of stripline	10 cm	10 cm
Stripline impedance	50 ohm	50 ohm
power for deflector	1kW $\times$ 4	1kW $\times$ 4
Number of deflectors	10	10
Number of driver amp	40	40
Damping time	0.90 msec	2.1 msec

Figure 6: Schematic diagram of the feedback system used in the scheme for filling all of the buckets.

Figure 7: Minimum tune spread required to damp the instability as a function of the HOM impedance.

Longitudinal decoupling

To damp coherent dipole oscillation in the longitudinal direction, we will make bunch-to-bunch synchrotron-tune spread the same as one-fifth filling scheme. Figure 7 shows the minimum tune spread required to damp the instability as a function of the longitudinal impedance.

4. Summary

We don't require any damper system for the coupled-bunch instabilities in the one-fifth filling scheme. In order to achieve a safety factor, however, we plan to use side-band cavities to create a synchrotron tune spread among bunches; we also plan to use an active damper system in the transverse direction. Both systems are quite feasible.

Although it requires extensive R&D work, we might be able to cure the coupled-bunch instabilities in the scheme for filling all of the buckets on the basis of an extension of the techniques to be used for the one-fifth filling scheme: the synchrotron tune spread in the longitudinal direction and active feedback in the transverse directions.

Crab Cavity for the KEK B-Factory

K. Akai

1. Crab Crossing Schemes

At the KEK B-Factory, in order to attain a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$, we should probably fill every RF bucket with beams. In this case the bunch spacing is only 0.6 m. To realize this, a finite angle crossing scheme is a powerful solution. However, experience concerning storage rings with a finite crossing angle have shown lower beam-beam limits due to synchrotron-betatron coupling resonances.^{1),2)} In order to overcome the problem, a crab crossing scheme, which was first proposed by R.B. Palmer³⁾, has to be challenged to realize a large crossing angle.

In the crab crossing scheme, RF deflectors are located at the positions where the betatron phase advance is $\pi/2 + n\pi$ (n is an integer) from the interaction point (IP). Bunches are tilted by a transverse kick in an RF deflector before the IP and kicked back to the original orientation in another deflector after the IP. Four RF deflectors are required for two rings.

The RF phase of the deflector should be set such that the deflecting voltage is zero when the bunch center passes the deflector. One of the most promising candidates for the deflector is the use of crab cavities operating in the TM110 mode. In this mode the bunch is kicked transversely by the transverse electro-magnetic field on the axis.

2. Requirements for the Crab Cavity

2.1 Deflecting Voltage

The necessary transverse deflecting voltage is determined by the desired crossing angle at the IP and operating frequency of the crab cavity as

$$V_0 = \frac{cE \tan \varphi}{\omega_{rf} \sqrt{\beta^* \beta_{crab}}}, \quad (1)$$

where β^* , β_{crab} , E , φ and ω_{rf} are the beta-function at the IP, the beta-function at the crab cavity, the beam energy, the half crossing angle and the RF frequency of the crab cavity, respectively. Table 1 summarizes the basic parameters for the crab cavities in cases of the 3.5- and 8.0-GeV rings of the KEK B-Factory. The necessary deflecting voltages are 0.82 and 1.88 MV for the LER and the HER, respectively.

2.2 Parasitic Modes

Multibunch instabilities should also be taken care of in the crab cavities, as well as in the accelerating cavities. The Q-values of the higher-order modes (HOMs)

Table 1: Parameters for the crab cavity of the KEK B-Factory.

		LER	HER	
Energy	E	3.5	8.0	GeV
Beam current	I	2.6	1.1	A
β^*		1.0	1.0	m
β_{crab}		100	100	m
Deflecting voltage	V_o	0.82	1.88	MV
$(\varphi=25 \text{ mrad and } \omega_{rf}=2\pi\times 508\text{MHz})$				

should be sufficiently lowered. In addition to the HOMs, two other modes should be adequately damped. One is the TM110 mode whose orientation is rotated axially by $\pi/2$ with respect to the TM110 mode that is used to tilt the bunch. The other mode to be damped is TM010, whose frequency is lower than that of TM110.

2.3 Tolerances

The phase error of the deflecting RF field causes a relative transverse displacement of both beams at the collision point. The tolerance for this error is estimated⁴⁾ as

$$\Delta\theta \ll \frac{\omega_{rf}}{c \tan \varphi} \sigma_x^*. \quad (2)$$

An amplitude error of the deflecting RF field causes an error regarding the tilt angle and excites synchrotron-betatron resonances. The tolerance is⁴⁾

$$\frac{\Delta V}{V} \ll \frac{\sigma_x^*}{\sigma_z \tan \varphi}. \quad (3)$$

In (2) and (3), σ_x^* and σ_z are the horizontal beam size at the IP and the longitudinal bunch length.

Taking $\varphi=25 \text{ mrad}$, $\omega_{rf}=2\pi\times 508 \text{ MHz}$, $\beta^*=1.0 \text{ m}$, $\beta_{crab}=100 \text{ m}$, $\epsilon_x=1.85 \times 10^{-8}\text{m}$ and $\sigma_z=0.005 \text{ m}$, these tolerances are $\Delta\theta \ll 3.3 \text{ deg}$ and $|\Delta V/V| \ll 1.1$. It should be noted that the accuracy requirement for the phase is remarkably strict.

The relative displacement of the beam orbit and the cavity center should be kept small. When bunches pass off-axis, a longitudinal electric field causes energy gain or energy loss of the bunches. As far as the energy deviation is concerned, a rather large displacement is tolerable. The tolerance for the displacement is related to the power handling ability of the RF system, such as the input coupler and the window, since a large displacement causes an exchange of a large amount of beam power. The beam loading power is estimated to be about 100 kW when bunches pass 5 mm off-axis, assuming that the crab cavity is a single-cell pill-box-type cavity.

3. Design of Single Cell Crab Cavity

3-1. Cell Shape

In order to reduce the impedance of HOMs, fewer cells are desirable for the crab cavity. We started to design a single-cell crab cavity in order to examine whether this type of cavity can work as a crab cavity for the KEK B-factory supplying the necessary deflecting voltage.

The transverse deflecting voltage is related to the transverse R^*/Q calculated with URMEL as

$$V_0 = \sqrt{\left(\frac{R^*}{Q}\right) \times \omega_{rf} W}, \quad (4)$$

where W is the stored energy and R^*/Q , which is obtained from the URMEL calculation, is

$$\frac{R^*}{Q} = \frac{|\int E_z(r=r_0)e^{jkz}dz|^2}{(kr_0)^2 \omega_{rf} W}. \quad (5)$$

In (5), k and $E_z(r=r_0)$ are the wave number and the longitudinal electric field calculated off axis by a distance r_0 , respectively.

The cell shape is optimized so as to have higher R^*/Q of the crab mode (TM110) and lower R^*/Q of other modes. Figure 1 shows the cell shape used for the calculation. Figure 2 shows the frequency of main longitudinal modes and the cut-off frequency of TM01 mode in the beam pipe as a function of the beam pipe radius. If the beam pipe radius, R_b , is larger than 160 mm, TM020 and TM011 can propagate down the beam pipe. Increasing the beam pipe radius, on the other hand, makes R^*/Q for the crab mode (TM110) smaller, as is shown in Fig. 3. However, we will take advantage of the propagating TM011 and TM020, as far as the needed deflecting voltage can be provided. We thus take $R_b=165$ mm in the following. TM010 and TE111, however, can not propagate down the beam pipe, even if we take $R_b=165$ mm. Figure 4 shows the dependence of R^*/Q of the crab mode on the radius of iris, R_{iris} , and the cavity length, d . Figure 5 shows the dependence of R^*/Q of the TE111 mode on R_{iris} and d . Changing R_{iris} and d we can optimize R^*/Q of the crab mode and can reduce R^*/Q of TE111 by some factor. By taking these arguments into account, the cell shape can be optimized. Resonant modes of the best cell shape achieved until now are summarized in Table 2.

The surface peak electric field (E_{sp}) is 11.4 MV/m for the LER and 26.1 MV/m for the HER. The surface peak magnetic field (H_{sp}) is about 300 Oe for the LER and 700 Oe for the HER. E_{sp} of 20 MV/m and H_{sp} of 400 Oe have already been achieved with 5-cell 508 MHz superconducting cavities operating in TRISTAN at KEK. As for single cell 1.5 GHz cavities, E_{sp} of 60 MV/m and H_{sp} of 1500 Oe have been achieved at Cornell. Single cell crab cavities for the LER and the HER can thus provide the necessary deflecting voltages using existing superconducting

Table 2: Resonant modes of the single cell crab cavity.

Crab mode (TM110)		
freq.	508 MHz	
R/Q	25 Ω /cell	
E_{sp}/Vo	13.9 (MV/m)/MV $\rightarrow E_{sp}=11.4$ MV/m (LER), 26.1 MV/m (HER)	
H_{sp}/Vo	373 Oe/MV $\rightarrow H_{sp}=306$ Oe (LER), 701 Oe (HER)	
Longitudinal modes		
	freq.	R/Q
TM010	389 MHz	72 Ω /cell
TM020	705 MHz	above cut off
TM011	712 MHz	above cut off
Transverse modes		
	freq.	R/Q
TE111	501 MHz	2.8 Ω /cell
TM110	508 MHz	25 Ω /cell
TM120	963 MHz	above cut off
Input data: $R_b=165$ mm, $\theta=75$ deg, $R_{iris}=60$ mm and $d/2=150$ mm.		

cavity technology. If we use single cell normal conducting cavities, the power loss at the cavity surface is over 1 MW. Taking into consideration of RF windows and cooling capability, more than 5 cells are needed for each crab cavity.

3-2. Cure for the Parasitic Modes

As described above, there exist four non-propagating parasitic modes (TM010, two polarizations of TE111 and one of two polarizations of TM110). Other HOMs can propagate down the beam pipe. For the propagating HOMs, Q_{ext} can be reduced with some absorbers attached at the beam pipe, as was proposed at Cornell for the cavities of CESR-B⁵⁾. At Cornell, a kind of ferrite is being tested as an absorber, showing good vacuum performance.⁶⁾

As for the non-propagating modes, if we require that the impedance of the crab cavity should be smaller than that of the accelerating cavities, the allowable Q_{ext} is estimated as⁷⁾

$$\begin{aligned}
 Q_{ext} &< 170 && \text{for TM010,} \\
 Q_{ext} &< 1800 && \text{for TM110, and} \\
 Q_{ext} &< 10000 && \text{for TE111,}
 \end{aligned}$$

taking R^*/Q calculated with URMEL. Possible methods to avoid the multi-bunch instabilities are:

1. Reducing the Q_{ext} with HOM couplers.
2. Tuning each modes at a safe frequency with tuners.
3. Damping them actively with some feedback method.

Coaxial-type HOM couplers used in superconducting cavities for TRISTAN at KEK and those for HERA at DESY have shown typical reduction of Q_{ext} of TM110 and TE111 to the order of a few $\times 10^3$. We expect that also in the crab cavity Q_{ext} of TM110 and TE111 can be sufficiently reduced with HOM couplers.

As for the TM010 mode, we have not confirmed that the Q_{ext} can be sufficiently reduced with couplers. We will probably have to tune this mode at a safe frequency. When buckets are filled with equal current of beams and with equal bunch spacing, beam lines are separated apart by $f_{rev} \times N$, where f_{rev} is the revolution frequency and N is the number of bunches. However, beam lines may appear at every harmonics of f_{rev} due to missing buckets or unequal bunch current. We thus have to tune this mode apart by half of f_{rev} from the harmonics of f_{rev} . It is possible to tune this mode at the safe frequency keeping the frequency of the crab mode unchanged. The revolution frequency is 235 kHz and the accuracy required for the tuning of TM010 is expected to be of the order of 10 kHz. The tuner for this mode is not necessarily an active one with feedback, in contrast to an active tuner for the crab mode.

Summary

Single cell superconducting crab cavities for the LER and the HER can provide the necessary deflecting voltages. R&D of HOM couplers, tuning system, absorbing material and accurate control of the phase stability are necessary.

Acknowledgements

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Figure Captions

Fig. 1 The cell shape of the single-cell crab cavity used for the calculation.

Fig. 2 The frequencies of main longitudinal modes and the cut-off frequency of TM01 mode in the beam pipe as functions of the beam pipe radius.

Fig. 3 The dependence of R^*/Q of the crab mode (TM110) on the beam pipe radius.

Fig. 4 The dependence of R^*/Q of the crab mode (TM110) on the radius of the iris and the cavity length.

Fig. 5 The dependence of R^*/Q of TE111 mode on the radius of the iris and the cavity length.

Figure 1: The cell shape of the single-cell crab cavity used for the calculation.

Longitudinal modes

Figure 2: The frequencies of main longitudinal modes and the cut-off frequency of TM01 mode in the beam pipe as functions of the beam pipe radius.

Figure 3: The dependence of R^*/Q of the crab mode (TM110) on the beam pipe radius.

Figure 4: The dependence of R^*/Q of the crab mode (TM110) on the radius of the iris and the cavity length.

Figure 5: The dependence of R^*/Q of TE₁₁₁ mode on the radius of the iris and the cavity length.

Vacuum System for the KEK B-Factory

K. Kanazawa, Y. Suetsugu and Y. Hori

The design principle for the vacuum system of the KEK B-Factory is to be conservative. It will thus use well-established techniques based on the present available experience concerning electron rings. The following is an outline of the vacuum system design for the arc section of the KEK B-Factory.

1. Pressure Requirement

Beam lifetime

Assuming that the ring has a sufficient geometrical aperture, the beam lifetime is limited by the bremsstrahlung process in which a particle in a bunch losses energy by radiation during a collision with a nuclei of the residual gas and gets out of a momentum aperture. The lifetime determined by this process must be much longer than the luminosity lifetime and must be adequately long to meet the injection scheme. The lifetime (τ) is related to the average pressure (P) as

$$P\tau=5.6 \times 10^{-6} \text{ [Pa}\cdot\text{hour]},$$

for $\Delta p/p=0.01$. We assume that the residual gas is CO for simplicity. For example, the pressure of 1×10^{-7} Pa allows a beam lifetime of 56 hours; this is sufficiently long.

Ion trapping

From experience at the KEK Photon Factory, it is known that ion trapping causes no serious effect if the pressure is below 10^{-7} Pa (S. Sakanaka, private communication). The electron ring (HER) must thus have a pressure lower than 10^{-7} Pa.

Detector background

To make the background on the detector sufficiently small, the average pressure around the colliding point and in the arc section should be less than some value. For the KEK B-Factory, 1×10^{-7} Pa is required around the colliding section.

From these considerations, the required pressure with the full design beam current is set at 10^{-7} Pa both for HER and LER.

2. Heat and Gas Load due to Synchrotron Radiation

The amount of synchrotron radiation, calculated on the basis of the machine parameters of the KEK B-Factory, is listed in Table 2. The beam currents are those

for a goal luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$. The fields of the wiggler magnets represent for the strongest case. The horizontal half aperture of a beam duct in the arc section is taken to be 50 mm to provide a high conductance.

Table 1: Parameters of synchrotron radiation.

	LER	HER	
Energy	3.5	8.0	GeV
Beam Current	2.6	1.1	A
<u>In normal cell</u>			
Bending Radius	14.4	90.9	m
Critical Energy of SR	6.61	12.5	keV
Total SR Power	2.40	4.39	MW
Total SR Photon	7.35×10^{21}	7.11×10^{21}	photons/s
Power Density (Max.)	5.69	7.68	kW/m
Photon Density (Average)	8.53×10^{18}	8.25×10^{18}	photons/s/m
<u>In one wiggler section</u>			
Magnet field	1.42	0.67	Tesla
Total SR Power	2.5	1.3	MW
Total SR Photon	4.3×10^{21}	9.1×10^{20}	photons/s
Power Density	30 ~ 40	~20	kW/m
Photon Density	$5 \sim 7 \times 10^{19}$	1.4×10^{19}	photons/s/m

The vertical spread of synchrotron radiation at the chamber wall is about 0.4 ~ 1 mm.

In a straight section with wiggler magnets, the load of synchrotron radiation is more stringent than in a normal cell. Moreover, in HER, about 30% of the total power enters into the bending magnets next to the wiggler section and a local power density rises as high as 87 kW/m. In LER, about 17% of the total power enters into the adjacent bending section and the peak local power density is 74 kW/m. The synchrotron radiation from the wiggler magnets also causes gas desorption; however, the heat due to the radiation is a much more serious problem for beam ducts. To consider a vacuum system, a wiggler section and a bending magnet next to the wiggler section are to be treated separately from a normal cell.

3. Vacuum Design

Chamber material

Common materials for a beam duct are stainless steel, copper and aluminum.

Due to rather high heat load, the use of stainless steel for a part exposed to synchrotron radiation will be excluded. Copper has the best physical properties for the B-Factory, i.e. high thermal conductivity, high melting point, and a low photon desorption coefficient[1]. It is also useful as a shield for radiation. Although there already exists an accelerator whose beam ducts are made of copper[2], it is difficult to fabricate a beam duct with a complicated cross section from copper. We have a reliable technique on aluminum vacuum system through the construction of TRISTAN; aluminum, however, cannot be used for a part where the radiated power is more than 10 kW/m. For a higher heat load copper must be used. Therefore, a beam duct in a normal cell will be made of aluminum, and that for a wiggler section and bending magnet next to the wiggler will be made of copper.

The decrease of the photon desorption coefficient (η) with integrated photon dose deduced and extrapolated from the data of TRISTAN Accumulation Ring (extruded aluminum) is shown in Fig. 1. This is for the critical energy of 1.6 $\sim$ 26 keV and the incident angle of about 3°; it is also applicable to our case where critical energies and incident angles are not much different.

Pumping system in a normal cell

The vacuum system in a normal cell is to be designed to achieve 10^{-7} Pa for a photon dose of 1×10^{19} photons/s/m for both rings. Under this photon dose, the relation among the average distributed pumping speed, the photodesorption coefficient(η), and the average pressure is shown in Fig. 2.

If we require, for example, to achieve 10^{-7} Pa when η is 1×10^{-6} molecules/photon, an average pumping speed of 400 ℓ /s/m is necessary. This is possible with the aid of not a few NEG's (Non Evaporable Getter) and Ti sublimation pumps, or with the help of cryo-pumps. We do not, however, pursue this possibility in this design, since we think it goes beyond the conventional design.

An average distributed pumping speed of 100 ℓ /s/m at 10^{-7} Pa is possible with a conventional design using ion pumps and distributed ion pumps combined with NEG or Ti sublimation pumps. As can be seen from Fig. 2, to achieve 1×10^{-7} Pa, it is necessary to reduce η to 2.5×10^{-7} molecules/photon by conditioning. To reach this η , 2800 hours of operation under full current (10^{26} photons/m) is required for an aluminum system (see Fig. 1). If the average operation current is 20% of the full current, 580 days of operation are necessary. This implies that, at least, we require a pumping speed of 100 ℓ /s/m.

For wiggler sections and bending magnets next to the wiggler section, no more pumping speed is required, because the photon dose in these sections is larger than that in a normal cell and η decreases more quickly compared to in a normal cell.

4. Design Drawings

Figure 3 shows the conventional design for a normal cell of the KEK B-Factory.

The main pumps are ion pumps. NEG's are added to increase the total pumping speed and to compensate for any decrease in the pumping speed of ion pumps in the $10^{-6} \sim 10^{-7}$ Pa range. Calculated distributed pumping speed and the pressure distribution when η is 10^{-6} molecules/photon are shown in Fig. 4.

5. Required R&D

To realize a more powerful vacuum system for the B-Factory, the following R&D is necessary:

1. To establish a reliable technique to fabricate copper beam ducts;
2. To develop a high pumping speed pump;
3. To study surface treatments to reduce η .

Acknowledgement

We sincerely thanks Professor M. Kobayashi for valuable discussion.

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- [2] R. Ballion *et al.*, The Vacuum System of the HERA Electron Storage Ring, in Particle Accelerators 29 pp. 145-152 (1990).

Figure Captions.

Fig. 1 Decrease of photon desorption coefficient (η) in TRISTAN Accumulation Ring.

Fig. 2 Relation of distributed pumping speed, photon desorption coefficient, and average pressure at a photon irradiation of 10^{19} photon/s/m.

Fig. 3 Vacuum design of a normal cell for the KEK B-Factory.

Fig. 4 Calculated distributed pumping speed (top) and pressure distribution at $\eta=1 \times 10^{-6}$ (bottom). Gas desorption is assumed to be proportional to the primary photon distribution (a) LER and (b) HER.

Figure 1: Decrease of photon desorption coefficient (η) in TRISTAN Accumulation Ring.

Figure 2: Relation of distributed pumping speed, photon desorption coefficient, and average pressure at a photon irradiation of 10^{19} photon/s/m.

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{one normal cell}
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[One normal cell]
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Figure 3: Vacuum design of a normal cell for the KEK B-Factory.

(a)

(b)

Figure 4: Calculated distributed pumping speed (top) and pressure distribution at $\eta = 1 \times 10^{-6}$ (bottom). Gas desorption is assumed to be proportional to the primary photon distribution (a) LER and (b) HER.

Average Luminosity and Injection Scheme

K. Satoh

1. Beam Lifetime

The beam lifetime in the collider ring is determined by two kinds of beam loss mechanisms. One type is related to such single-beam phenomena, as the quantum radiation effect, the scattering by residual gas and the Touschek effect. The other is associated with beam collision.

Among the single-beam phenomena the Touschek effect is most important in determining beam lifetime, especially in the low-energy ring. The Touschek lifetime depends on the momentum acceptance as well as the energy of the ring, and is estimated to be 7.5 hours for the low-energy ring and much longer in the high-energy ring. By utilizing a suitable vacuum system we expect that the beam lifetime determined by the vacuum would be sufficiently long. If the luminosity per single collision is large, the beam lifetime is also restricted by beam collision. There exist two main processes, whose cross sections were found in a paper by F.Porter.^[1]

In this report we only show the results instead of rewriting the cross section formula. The first process is energy loss due to bremsstrahlung; its cross section depends on the momentum acceptance of the ring. If we assume an acceptance of 1.0% in both rings, the cross section is the same in the two rings and would be $2.6 \times 10^{-25} \text{cm}^2$. The second process is deflection by Bhabha scattering; its cross section depends on the beam energy and the betatron acceptance of the ring. If the acceptance of both rings is $1.2 \times 10^{-5} \text{m}$ with β_x^* of 1 m, the maximum deflection angle is 3.5 mrad. The cross sections are $4.4 \times 10^{-27} \text{cm}^2$ and $1.6 \times 10^{-28} \text{cm}^2$ for the low- and high-energy rings.

These results show that the energy loss by bremsstrahlung as well as the Touschek effect plays an important role in determining the beam lifetime. We only consider bremsstrahlung in the high-energy ring, and bremsstrahlung and the Touschek effect in the low-energy ring.

2. Luminosity Decay Rate

The decay rate in the total number, $N_i(t)$, of particles due to beam collision is

$$\frac{dN_i(t)}{dt} = -\sigma_i \mathcal{L}(t),$$

where $i = 1, 2$ for the low- and high-energy rings, respectively. Note that the cross

section, σ_i , due to bremsstrahlung is the same in the two rings and is denoted by σ . The instantaneous decay time, $\tau_i(t)$,

$$\tau_i(t) = \frac{N_i(t)}{\sigma \mathcal{L}(t)},$$

has the smallest value at peak luminosity, just after the colliding operation starts. In order to simplify the rate equation we assume that the decay time is constant and is evaluated at the peak luminosity. This assumption leads a slight underestimate of the average luminosity. The constant decay time of the number of particles is given by

$$\tau_i = \frac{N_{i0}}{\sigma \mathcal{L}_0},$$

where N_{i0} is the required number of particles at the peak luminosity, $\mathcal{L}_0$. In the case of the head-on colliding option, where

$$\mathcal{L}_0 = 2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1},$$

$$N_{10} = 1.4 \times 10^{13}, \text{ and } N_{20} = 5.8 \times 10^{12},$$

decay times τ_1 and τ_2 are 7.3 and 3.1 hours. If a Touschek lifetime of 7.5 hours is considered in the low-energy ring, the decay time τ_1 decreases to be 3.7 hours. The exponential decay time τ_L of the luminosity is then obtained by

$$\frac{1}{\tau_L} = \frac{1}{\tau_1} + \frac{1}{\tau_2},$$

and is 1.7 hours.

3. Optimum Operation Condition

When the refilling time is T_F and the experiment time is T_E under stationary operation, the average luminosity is

$$\bar{\mathcal{L}} = \frac{1}{T_F + T_E} \int_0^{T_E} \mathcal{L}_0 e^{-\frac{t}{\tau_L}} dt = \frac{\tau_L \mathcal{L}_0}{T_F + T_E} [1 - e^{-\frac{T_E}{\tau_L}}].$$

For fixed τ_L and T_F the optimum T_E is obtained by

$$\left. \frac{d\bar{\mathcal{L}}}{dT_E} \right|_{\tau_L, T_F} = 0,$$

which leads to the optimum condition,

$$\frac{T_F + T_E + \tau_L}{\tau_L} e^{-\frac{T_E}{\tau_L}} = 1.$$

If $T_E/\tau_L \ll 1$, the condition becomes

$$\frac{T_E}{\tau_L} \simeq \sqrt{2 \frac{T_F}{\tau_L}}.$$

Under the optimum condition the average luminosity is

$$\bar{\mathcal{L}} = \frac{\tau_L \mathcal{L}_0}{T_F + T_E + \tau_L}.$$

4. Injection by AR

We plan to inject positrons into the low-energy ring and electrons into the high-energy ring. During the early stage of the B-Factory the TRISTAN accumulation ring(AR) is to be employed as an injector. The present injector of AR is a 2.5 GeV PF linac. For this reason the injection rate into the B-Factory depends on the linac beam intensity, especially in the positron case, and also the acceleration cycle of AR.

The present positron injection rate into AR is 30 mA per minute at 50 Hz. This shows the linac accelerates 8×10^7 positrons per pulse in the single-bunch mode. We expect that the linac is able to inject positrons at a rate of 100 mA/min into AR, about 2.7×10^8 positrons per pulse at 50 Hz, by improving the positron production system and taking the multi-bunch mode. The electron injection rate into AR is to be easily raised up to the same value of 100 mA/min with a lesser effort.

Supposing that the both rings are empty, we estimate the time period required for filling the B-Factory during initial operation. The total current in the head-on option is 0.52 and 0.22 A for the low- and high-energy rings. We assume that each bunch is filled to the required bunch current by a single transfer from AR. In positron injection we plan to fill the low-energy ring using 22 AR cycles. Each AR cycle accelerates 20 bunches with a total current of 80 mA. The entire cycle of AR is 1.5 min, most of which is devoted to acceleration and deceleration. Initial positron injection thus needs about 35 minutes. In electron injection the high-energy ring is to be filled by 11 AR cycles, each of which accelerates 40 bunches with 70 mA in total. Electron injection takes about 20 minutes. As a result, the total injection period would be within 1 hour.

In order to realize this injection scenario, however, we need to improve AR so as to accelerate the multi-bunched beam with high current. The present AR has 8 sets of 9-cell APS cavities. In multi-bunch operation they would induce coupled bunch instabilities and limit the total current. We plan to stabilize the the beam with powerful feedback systems, but in the worst case need to replace these cavities with the same type damped-cavities as in the B-Factory. The present maximum

current at the highest energy of 8 GeV is 20 mA and is limited by the synchrotron radiation power on ceramic ducts. This problem is to be solved by reforming the beam duct.

The average luminosity depends on refilling time, T_F , and the luminosity lifetime, τ_L . In the refilling each beam in the collider is filled up by about 10 AR cycles. The total refilling of the B-Factory needs about 20 AR cycles and takes half an hour. From the estimated T_F of 0.5 hours and τ_L of 1.7 hours the average luminosity would be $0.5 \times \mathcal{L}_0$ and the optimum experiment period 1.1 hours. Most of the injection time of the B-Factory is consumed by the acceleration and deceleration of AR, not by the injection into AR from the linac. As long as AR is employed as the injector of the B-Factory the injection time cannot be effectively reduced by upgrading the linac beam intensity.

5. Injection in the Design Goal

At the design goal luminosity of $1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ a great deal of current is required. AR does no longer work for the B-Factory because of its too slow cycle. In order to maintain a reasonable average luminosity a new injector, for example, a rapid cycle synchrotron or an 8 GeV linac, is definitely necessary. In this section we assume the construction of a powerful new injector and estimate the average luminosity. At the same time the linac beam intensity is assumed to be ten times the present value both for the positron and electron beams. We expect that the new injector transfers 8×10^8 particles per pulse at 50 Hz for both electrons and positrons into the B-Factory.

First consider an operation start of the collider, where no beams are present. The total number of the positrons and electrons is 6.9×10^{13} and 2.9×10^{13} , respectively. Then the injection time for the positron and electron beams is 0.5 and 0.2 hours. The total filling time would be less than 1 hour.

The average luminosity depends on the refilling time T_F and the luminosity lifetime τ_L . Notice that the beam lifetime and the luminosity lifetime are the same as those in the head-on option, since the luminosity per collision is not changed between the two options. With the new injector, however, the refilling time depends largely on the number of particles injected at each refilling into the collider. The number of particles, ΔN_i , lost during the experiment time T_E is given by

$$\Delta N_i = N_{i0}/\tau_i \times T_E(h).$$

These particles have to be refilled during positron- and electron-injection times of T_1 and T_2 ,

$$\Delta N_i = 8 \times 10^8 \times 50 \times 3600 \times T_i(h).$$

The total injection time is

$$T_F = T_0 + T_1 + T_2,$$

where T_0 is used for the exchange the injection and experiment modes. Since T_i is proportional to T_E we have $T_F = T_0 + \alpha T_E$, with $\alpha = 0.20$ in our case. With this T_F the average luminosity is given by

$$\overline{\mathcal{L}} = \frac{\frac{\tau_L \mathcal{L}_0}{1+\alpha}}{\frac{T_0}{1+\alpha} + T_E} [1 - e^{-\frac{T_E}{\tau_L}}].$$

Comparing this equation with the former one, we find the optimum experiment time and the average luminosity by changing the refilling time from T_F to $\frac{T_0}{1+\alpha}$ and the peak luminosity from $\mathcal{L}_0$ to $\frac{\mathcal{L}_0}{1+\alpha}$ in the average luminosity equation. For example, if T_0 becomes as short as 3 minutes the average luminosity would be 67% of the peak luminosity. The optimum experiment time would be 22.5 min and the total refilling time is 7.4 minutes. One operation cycle of the B-Factory is about 30 minutes.

Reference

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Multibunch Operation in the TRISTAN Accumulation Ring

E. Kikutani

In the KEK B-Factory, the target luminosity will be achieved in two steps. In the first step, where every fifth RF bucket are filled with a bunch, the TRISTAN Accumulation Ring (AR) will be used as an injector to the collider rings. Here, we discuss the feasibility of multibunch AR operation.

1. Description of AR

AR is now used as an injector to the TRISTAN Main Ring and as a synchrotron radiation source. The main parameters of AR are listed in Table 1 and its schematic view is shown in Fig 1.

Table 1: Main parameters of AR.

Circumference	377 m
Bending radius	23 m
Momentum compaction	0.013
Maximum energy	8 GeV
RF frequency	508.58 MHz
Harmonic number	640
Injector	2.5 GeV e^+ , e^- linac

2. A Scheme of the Multibunch Storage

In Table 2 machine parameters which concern the injection scheme are summarized. When AR is used as the injector to the B-factory rings, it must store many bunches simultaneously to shorten the injection time. Bunches from the linac are stored successively to make a bunch train in AR. The length of the train is limited by the time for which extraction kicker magnets can hold sufficient voltage. The bunch current in AR is determined by that in the collider rings, 0.54 mA for HER and 1.28 mA for LER. When we try to transfer the full current for each bunch of the collider rings at one time, the bunch current in AR is 1.7 mA for electron bunch and 4.1 mA for positron bunch.

Considering these, a scheme of multibunch operation is determined as follows:

Figure 1: A schematic view of AR.

Table 2: Machine parameters concerning the injection.

	AR	HER	LER
injection energy	2.5 GeV	8 GeV	3.5 GeV
RF frequency	508.58 MHz		
harmonic number	640	2160	
particle	e^-/e^+	e^-	e^+
bunch current	1.7/4.1 mA	0.54 mA	1.28 mA

e^- : 1.7 mA $\times$ 40 bunches 5 RF buckets spacing (10 nsec)
 e^+ : 4.1 mA $\times$ 20 bunches 10 RF buckets spacing (20 nsec).

3. RF System

As explained in the previous section, bunch spacing is 10 and 20 nsec and the numbers of bunches are 40 and 20. Under this situation, coupled bunch instabilities will be very serious with ordinary accelerating cavities. We thus made a scenario in which the KEK damped cavities are used in AR as well as in the collider rings. Because the performance of the damped cavity is given in paper#9 of this report, we now list only the main parameters of the cavity in Table 3.

Table 3: Performance of the KEK damped cavity.

number of cells in one cavity	2
frequency of acceleration mode	508.58 MHz
Q of acceleration mode	27,500
impedance of acceleration mode	18.3 M Ω /m
length of one cavity (including flanges)	$\sim$ 0.9 m

Number of cavities and required power

The number of cavities and required RF power are determined by parameters listed in Table 4.

Table 4: Parameters of AR concerning RF system.

	e^-	e^+
total beam current (mA)	69	81
radiation loss (MeV/turn)	15.3 @ 8 GeV	0.57 @ 3.5 GeV
required acc. voltage (MV)	26	4

The highest required voltage, 26 MV, and the shunt impedance of the cavity gives the necessary number of cavities, 32, considering the cooling power of $\sim$ 60 kW per cavity. In this case the power passing through an input coupler is 93 kW, which is low enough. Table 5 summarizes the power requirement at 8 GeV with 40 electron bunches.

Installation of the cavities

Table 5: Power requirement of AR.

Beam power ($U_0 \times I_{total}$)	1.06 MW
Number of cavities	32
Wall loss in cavities	60 kW /cavity
Coupler power	93 kW/coupler
Total RF power	~ 3 MW

In AR, there are four long straight sections; two of them (the west and the east) are used for accelerating cavities. The long straight section for cavities has four drift spaces as shown in Fig. 2. Each drift space is occupied by 4 two-cell damped cavities (3.6 m in length).

Figure 2: RF section of AR.

Klystrons

At present two 1 MW klystrons (each in the east and in the west facility building) are used to feed power to the APS cavities. Because the total required power for the multibunch operation is 3 MW, we will add a 1 MW klystron in each building.

4. Estimation of Coupled Bunch Instabilities

The parameters of the higher order modes of the KEK damped cavities are given in the paper#9 of this report. The coupled bunch-instabilities are most

serious at 2.5 GeV, which is the injection energy of AR. The growth times for main higher-order modes are estimated at this energy. Table 6 shows the results and the radiation damping time as reference.

Table 6: Expected growth time (msec) of coupled bunch instabilities.

mode-ID	electron	positron
<i>Longitudinal modes</i>		
<i>rad. damp. time</i>		21.5
TM011- π	6.72	88.2
TM012-0	2.07	5.19
TM012- π	487	1532
<i>Transverse modes</i>		
<i>rad. damp. time</i>		43.1
TM110-0	1.93×10^6	1.16×10^{11}
TM110- π	23.2	24.8
TM111-0	16.3	28.1
TM111- π	22.7	210
TE112-0	11.7	11.0

As listed above, the growth times of some higher modes are shorter than the radiation damping time; we must prepare some damper systems. The concept of the damper system is the same as that for the collider rings (see papers #10 and #11 in this report): in the longitudinal direction, a tune spread is made to decouple the oscillation and for the transverse directions, a bunch-by-bunch feedback system will be installed.

Upgrade of Injector Linac for B-Factory

S. Ohsawa, A. Enomoto, H. Kobayashi, S. Anami, T. Shidara and A. Asami

1. Abstract

The injector linac for both the Photon Factory (PF) and TRISTAN will also be used as an injector for the B-Factory. An upgrade is necessary in order to satisfy the requirements of the B-Factory. We describe the upgrade plan of the linac while concentrating on how to increase the intensity of the positron beam.

2. Introduction

The requirements for injection at the B-Factory are summarized as follows:

1. The positron injection energy to the B-Factory should be higher than 1.5 GeV. The linac, however, is also the injector of the PF ring, which demands a 2.5-GeV positron beam; thus, the energy must be fixed at 2.5 GeV.
2. The present TRISTAN accumulation ring (AR) will also be used as an accumulator ring for the B-Factory. Accumulation rates to the accumulator ring must be larger than 100 mA/min for positrons and electrons.

Since the electron beam current is sufficiently large, it is not necessary to discuss the electron beam intensity here. How to increase the positron intensity to meet the above-mentioned requirements is discussed below.

3. Present Status

3.1 Present accumulation rate

We briefly summarize the present status of the positron beams at the linac. Positrons are produced at a primary electron energy of 250 MeV. The repetition rate of the linac is 25 pulses per second (pps). We operate the linac for positrons in two modes: The pulse width and peak current of each mode at the end of the 2.5-GeV main linac are as follows:

$$\begin{array}{ll} e^+ & : 40 \text{ ns, } 2.0 \text{ mA, } (3 \text{ A}) \\ & : 1 \text{ ns, } 15 \text{ mA, } (12 \text{ A}) \end{array}$$

The values in parentheses indicate the current of the primary electron beam for each case. A positron charge of a 40-ns beam is 5-times as large as that of a 1-ns beam. The beam current in the linac is related to the accumulation rate into the AR as follows:

$$\frac{dI_{AR}}{dt} = I\tau f f_{AR}\eta \quad (1)$$

where $\frac{dI_{AR}}{dt}$ is the accumulation rate into AR; I the beam current in the linac; τ the pulse width of a linac beam; f the repetition rate of the linac; f_{AR} the revolution frequency of the AR; and η the injection efficiency. The present accumulation rate is 10 mA/min (as a conservative value). Increase of the positron beam by factor ten is necessary to satisfy the requirements of the B-Factory.

3.2 Expected factors in increasing the beam current

To increase the positron intensity the following improvements or modifications can be carried out:

1. Increasing the repetition rate.
2. Improvement of the positron-focusing system.
3. Increasing the primary electron-beam energy.
4. Using a long-pulse beam with a micro-beam structure.

Details are described below.

4. Upgrade of the Linac

4.1 Repetition Rate

The pulse rate of injection is presently 25 pps. The maximum allowable pulse rate of the linac is 50 pps. The accumulation rate is proportional to the repetition rate of injection. A test for increasing the injection rate up to 50 pps was carried out and preliminary results showed the possibility of operation at 50 pps. Forty klystrons are used in the linac; the fault rate of one klystron during one day is 0.6. If the fault rate of the klystron increases by a factor of two at 50 pps, the total fault number of 40 klystrons a day becomes 48. This fault rate would not be a serious problem.

4.2 Improvement of the positron-focusing system

Improvements of the focusing system downstream of the positron target is now being carried out. When an electron with an energy of E impinges on a heavy-metal target, the yield of positrons, n , is given by

$$\frac{n}{E} = \frac{d^2n}{Ed\Omega dP} \delta\Omega \delta P. \quad (2)$$

Increases in both the spatial and momentum acceptance, $d\Omega dP$, are pursued in these improvements. In the present positron-focusing system, we use a so-called quarter-wave transformer (QWT), where a very strong, short-distance magnetic field, B_i (effective length L), is applied just behind the positron-production target;

a solenoid magnetic field with a strength of B_f follows it and is applied to an accelerator guide until positrons obtain a certain amount of energy. Details of the improvements of the focusing system will be reported elsewhere[1]. The dependence of the yield on the QWT-field parameters is the following:

1. The spatial acceptance, $d\Omega$, is proportional to $1/L^2$;
2. The momentum acceptance, dP , is proportional to $B_f \times L$;
3. Consequently, $d\Omega dP$ is proportional to B_f/L .

The magnetic field strength, B_i , determines the central momentum of captured positrons: we are trying to make L shorter and B_f larger; the momentum acceptance increases by a factor of two and the spatial acceptance by a factor of 1.5.

4.3 Increasing the primary electron-beam energy

As described in equation (2), the yield of positrons is proportional to the energy of the electrons which impinge on the target. An electron beam with an energy of 250 MeV is now being used. If the target position is moved toward the downstream side of the linac and electrons with an energy of 500 MeV are used, the yield of positrons would increase by a factor of two. In this case, it is necessary to increase the total accelerating energy up to 3 GeV, 1.2 times as large as the present energy. For this improvement, reinforcement of the rf power is required by a factor of 1.4.

4.4 Using a long-pulse beam with a micro-beam structure

In the step-1 of the KEK B-Factory, beams are accumulated in every fifth rf-bucket. In order to realize this injection scheme, there are two possible ways :

1. Using a 1-ns beam which is injected into AR by shifting the timing.
2. Using a long-pulse beam containing 1-ns pulse trains spaced by 9.84 ns as shown in Fig. 1.

As described in 3.1, a 40-ns beam contains a charge that is 5-times as much as that of a 1-ns beam. The latter injection scheme is apparently advantageous when accurate beam spacing without satellite beams can be realized. The required beam will be produced by introducing a chopper and an SHB system, such as that illustrated in Fig. 2. A continuous beam from a gun is to be modulated horizontally by the first deflector operating at 50.8 MHz, and is chopped by a vertical scraper. The second deflector will be used to cancel the transverse momentum given by the first deflector. Then the beam will be bunched by an SHB at 101.6 MHz. Beam simulation by "PARMELA" predicts micro-beam structures, as shown in Fig. 3 at three points: the entrances of the deflector, the SIIB and the prebuncher.

The beam pulse width is assumed to be 200 ns, and the current of 0.6 A at the prebuncher in order that beam loading will be the same as the 40-ns, 3-A beam

Table 1: Total effect of the improvements.

	Case 1	Case 2
Repetition rate	2	2
Momentum acceptance	2	2
Spacial acceptance	1.5	1.5
Primary beam energy	1	2
Long pulse beam	5	5
Total	30	60
e^+ /sec	7.5×10^{10}	1.5×10^{11}

which is now being used for the PF ring. The simulation requires a beam of 2 A from the gun. This will be no problem since our gun has the ability to produce a beam of more than 10 A. The result of the simulation indicates that the required beam can be obtained by the system shown in Fig. 2.

4.5 Total effects

Table 1 summarizes the total effects of the improvements in the linac pulse repetition rate, the positron focusing system, the primary electron beam energy and the linac pulse structure. The second and the third column shows the relative positron increments due to each improvement as well as the integrated effects. The values in the final line are the positron intensities at 2.5 GeV. In case 1, the primary electron energy is 250 MeV; in case two, a 500 MeV primary beam is assumed. The factors for increasing the positron beam are roughly estimated.

5. Summary

For the B-Factory, the linac positron beam must be reinforced by roughly ten times. (The electron beam is sufficiently strong.) This reinforcement (which is the minimum requirement) could be realized by undertaking the integrated linac upgrade mentioned above. Details of the linac beam specification should be discussed during the next stage when the linac-to-ring injection design progresses.

References

- [1] A. Enomoto *et al.*, "Present status and reinforce plan of the KEK positron generator", 1990 Linear Accelerator Conference.

Figure 1: Beam micro-structure.

Figure 2: System configuration.

Figure 3: Micro-pulse structure.

Alignment and Support of Magnets

R. Sugahara

The precision required for magnet alignment is assumed to be $50\text{ }\mu\text{m}$ in r.m.s. for quadrupole and dipole magnets and $25\text{ }\mu\text{m}$ in r.m.s. for sextupole magnets in all places except for the colliding region. The precision of $25\text{ }\mu\text{m}$ in r.m.s. and the stability of $1\text{ }\mu\text{m}$ in r.m.s. is assumed to be required for magnet alignment in the colliding region. Magnets are to be aligned at the precision described above over a distance of one betatron wave-length, about 40 m. The alignment method and support is proposed in the following.

1. Alignment

Magnet alignment in the horizontal and the vertical directions perpendicular to the beam axis is to be carried out using a laser beam and QPD's, Quadrant Photo Detectors. It has been reported that the precision of this laser and QPD method is $20\text{ }\mu\text{m}$ in r.m.s.[1]. Splitting the laser beam and inverting the direction of movement of one of the laser spots by inserting mirrors, the errors caused by the spatial and the angular drift of the laser spot can be cancelled. It has been reported by the JLC, Japan Linear Collider, working group that the precision of $1\text{ }\mu\text{m}$ or better can be achieved by this method[2]. In order to achieve high resolution over a long distance, a vacuum tube must be installed all along the flight paths of the laser beam. Otherwise, the laser beam would refract according to the turbulence in the density of the air, and the accuracy for pointing by the laser spot would be much worse than $100\text{ }\mu\text{m}$ at a position 40 m far from the laser gun. The bases for the laser gun and the QPD's are to be equipped onto each magnet, and those are to be adjusted at the time of the magnetic field measurement using theodolites, since this traditional method is easy to handle and an accuracy of $20\text{ }\mu\text{m}$ or better can be achieved at a short distance of several meters. When the precision better than $20\text{ }\mu\text{m}$ is required, the laser and QPD system is to be used.

Alignment along the beam axis is to be performed by means of a traditional methods, such as using a dial gauge and an Invar line[3].

The tilt of the magnets is to be measured by means of a mercury pool. The level of the mercury surface in each pool tube is to be measured capacitively. An accuracy of $1\text{ }\mu\text{m}$ can be achieved[4]. Bases for the mercury pool are to be equipped at four $1\text{ }\mu\text{m}$ corners of each magnet; those are adjusted at the time of the magnetic field measurement. At this time magnets are being placed horizontally on the adjusting table, and bases for the mercury pool are adjusted so that all the mercury pool tubes show the same level.

2. Support

Seismic motion of the ground was measured by the JLC working group at the floor of the Fuji experimental hall, 16 m below the ground surface, in the TRISTAN collider[5]. The amplitude of fast motion, at a frequency higher than 1 Hz, was found to be much less than 1 μm . Thus the protection against only slow seismic motion, at a frequency less than 1 Hz, must be considered. Magnets installed in places other than the colliding region are to be supported by solid supporting benches on which the position and the tilt of magnets can be adjusted manually. The position and the tilt of each magnet must be surveyed periodically and adjusted in order to maintain the required precision.

The level of magnets in the colliding region must be measured continuously, and the displacement must be corrected in order to maintain the same position within 1 μm . The level at four corners of each magnet or each supporting table, on which several small magnets are placed together, is measured by means of the capacitive readout of the level of the mercury surface in the pool tubes equipped at each corner. All the magnets of the supporting tables are equipped with an automatic adjusting mechanism which uses micro-stepping motors or piezoelectric transducers, and the level and the tilt of the magnets or the tables are adjusted automatically according to the capacitive readout of the level of the mercury in the pool.

References

- [1] J. Billan *et al.*, CERN AT-MA/90-18.
- [2] K. Miyashita *et al.*, Internal report of JLCK working group.
- [3] K. Endo and A. Kabe, KEK Internal 86-12.
- [4] G.E. Fisher and M. Mayond, CERN-LEP-RF-SU-88-07, CLIC Note 61.
- [5] N. Ishihara *et al.*, Internal report of JLCK working group.

Tunnel and Buildings

H. Nakanishi

A layout of the KEK B-Factory is shown in Fig. 1. The tunnel has a race-track shape (see Fig. 2) and comprises two 140 m and two 50 m long straight sections and four 90° arcs with an average radius of ~ 140 m. The total circumference is about 1300 m. A 320-m tunnel connects the TRISTAN accumulation ring to this new tunnel. The experimental hall is located in the middle of a long straight section. Other buildings, such as the klystron building, magnet power supply buildings, utility buildings and control rooms are located on the ground surface.

1. Site

The depth of the tunnel should be minimized to reduce the construction costs and at the same time should be sufficiently large to keep the radiation level of populated areas within the designated limit. This is solved by constructing the tunnel floor 4 m below the ground surface. The soil from the ground surface to 8 m under it consists of ash and clay, with a high water content. Under this layer, there exists a sand layer 10 m thick with rocks under it. The tunnel will be supported by this layer with concrete piles of at least 10 m length.

2. Tunnel

The tunnel is to have inner cross sections of 6×4 m² and 8×5 m² in the long straight sections and 6×4 m² in the arcs. The tunnel will be made by a trench excavation method.

The cross section of tunnel in the arcs is shown in Fig. 3. In order to save space, we will not equip the tunnel with overhead cranes for magnet installation. Heavy machine components will be transported and installed by the use of custom-made vehicles. The midplane of the low energy ring (LER) and the high energy ring (HER) is 1.0 m above the floor level; the LER lies 2.4 m apart from the beam line of the HER. Magnets for the booster ring are mounted on stands placed over the magnets for the HER or LER.

The cross section of the tunnel in the long straight section for acceleration cavities is determined by big dummy loads of rf cavities. The cross section of the tunnel in the interaction region is mainly determined by the vertical and horizontal bends needed to bring the LER beam and the HER beam into collisions (See Fig. 4 and 5).

The tunnel connecting the B-Factory to TRISTAN accumulation ring is 320 m long and has an inner cross section of 2×2.5 m². This will also be made by a trench

excavation method.

3. Buildings

The experimental hall is to be located in the middle of the 140 m long straight section. The layout of the experimental hall is shown in Fig. 6. The floor space in the experimental hall is determined by the need to accommodate a large detector; the available floor space of $22 \times 30 \text{ m}^2$ should be compared to the $22 \times 33 \text{ m}^2$ of a typical TRISTAN experimental hall. The klystron building is located along the other long straight section. The floor space of this hall is 2500 m^2 .

The other buildings have the following areas:

a)	magnet power supply building	3000 m^2
b)	control rooms	2000 m^2
c)	beam transport building	350 m^2
d)	utility building	3000 m^2

4. Power and Cooling

Estimates of the power consumption for the KEK B-Factory are given below.

a)	rf system	18 MW
b)	magnets	20 MW
c)	vacuum, beam transport, control and experiment	5 MW
d)	utilities	$\sim 10 \text{ MW}$
	(total)	$\sim 53 \text{ MW}$

Figure Captions

Fig. 1 A layout of the KEK B-Factory.

Fig. 2 Configuration of the two rings.

Fig. 3 Tunnel cross section in the arc.

Fig. 4 Tunnel cross section in the long straight section for RF cavities ($D-D$) in Fig. 2.

Fig. 5 Tunnel cross section in the long straight section for interaction region ($A-A$) in Fig 2.

Fig. 6 A plan view of the experimental hall.

Figure 1: A layout of the KEK B-Factory.

Figure 2: Configuration of the two rings.

TYPICAL SECTION

Figure 3: Tunnel cross section in the arc.

Figure 4: Tunnel cross section in the long straight section for RF cavities (D-D) in Fig. 2.

Figure 5: Tunnel cross section in the long straight section for interaction region (A-A) in Fig 2.

Figure 6: A plan view of the experimental hall.

Appendix

Input Parameters of SAD

```

1- 28/08/90 103041626 MEMBER NAME \SADIN1 *.FORT SAD ---
| 8 GEV COLLIDER FOR THE KEK B FACTORY HEAD ON (\HR103B)
MOMENTUM= 8 GEV;
OFF ECHO;OFF EMIT COD CTIME RAD RFSW;

```

HER (head-on)

```

;
DRIFT LXS =(L = 0.3 ) LI1 =(L = 0.4 ) LI2 =(L = 1 )
      LX0 =(L = 0.2 ) LI3 =(L = 0.9 )
      LC30 =(L = 4.7306642725 ) LC40 =(L = 2.5 )
      LV50 =(L = 0.9448913985 ) LV40 =(L = 2 )
      LV20 =(L = 11.3092563528 ) LV10 =(L = 5.1480789962 )
      LV00 =(L = 2.4517425255 ) LC50 =(L = 6.668946235 )
      LS1 =(L = 0.4936511031 ) LS2 =(L = 8.0627478681 )
      LXS2 =(L = 0.7 ) L1 =(L = 0.5 ) LXSD =(L = 0.2 )
      L2 =(L = 0.25 ) LXS1 =(L = 0.9 ) LXSF =(L = 0.2 )
      LXW4 =(L = 0.23 ) LXW1 =(L = 0.68 ) LXW2 =(L = 0.48 )
      LXW3 =(L = 0.88 ) LXWOS =(L = 1.285 )
      LW0 =(L = 0.2 ) LW =(L = 0.2 )
      LR3S =(L = 5.0524705031 ) LR2S =(L = 2.0275798886 )
      LR1S =(L = 2.7549574739 ) LX1 =(L = 0.2 )
      LX2 =(L = 2.4962813378 ) LX3 =(L = 5.930152438 )
      LRF =(L = 3 ) LM2L =(L = 1.0097357114 )
      LM3L =(L = 6.7551831814 ) LM4L =(L = 2.7024289698 )
      LM5L =(L = 1.0471483428 ) LXWOL =(L = 2.985 )
      LCS1 =(L = 3.0999939947 ) LV0I =(L = 1.3384285652 )
      LV1I =(L = 8.1299778612 ) LV2I =(L = 8.9510097725 )
      LV4I =(L = 3.9326737926 ) LV5I =(L = 0.4872884531 )
      LC4I =(L = 10.9673133137 ) LC3I =(L = 7.8468940276 )
      LSEP =(L = 2.3 )

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BEND BS10 =(L = 0.2 ANGLE =-1.356E-3 )
      BS20 =(L = 0.2 ANGLE =-3.443E-3 )
      BS30 =(L = 0.2 ANGLE =-4.703E-3 )
      BS40 =(L = 0.2 ANGLE =-5.178E-3 )
      BQ10 =(ANGLE = 3.5475E-3 )
      BQ20 =(ANGLE = 2.847E-3 )
      BSEPO =(L = 1.9 ANGLE = 0.05 E1 = 0.025 E2 = 0.025
      ROTATE = 3.4377467708 DEG )
      VB30 =(L = 0.4 ANGLE =-2.91531786E-3 ROTATE = 90 DEG )
      BH10 =(L = 6 ANGLE = -0.05 E1 = -0.025 E2 = -0.025 )
      BH20 =(L = 5 ANGLE = -0.0119133263 )
      BH40 =(L = 5 ANGLE =-6.68176736E-3 )
      B =(L = 3.4 ANGLE = 0.0373999126 E1 = 0.018699956
      E2 = 0.018699956 )
      BW1 =(L = 0.5 ANGLE = 0 )
      BW2 =(L = 1 ANGLE = 0 )
      BW3 =(L = 1 ANGLE = 0 )
      BW4 =(L = 0.5 ANGLE = 0 )
      BT1 =(L = 6 ANGLE = -0.064 E1 = -0.032 E2 = -0.032 )
      BT2 =(L = 6 ANGLE = 0.064 E1 = 0.032 E2 = 0.032 )
      BH4I =(L = 5 ANGLE = 7.81250898E-3 )
      BH2I =(L = 5 ANGLE =-1.91637121E-3 )
      VB2I =(L = 0.4 ANGLE =-3.9763109E-4 ROTATE = 90 DEG )
      VB3I =(L = 0.4 ANGLE = 4.83844215E-4 ROTATE = 90 DEG )
      BS4I =(L = 0.2 ANGLE = 5.178E-3 )
      BS3I =(L = 0.2 ANGLE = 4.703E-3 )
      BS2I =(L = 0.2 ANGLE = 3.443E-3 )
      BS1I =(L = 0.2 ANGLE = 1.356E-3 )

;
QUAD QI1 =(L = 0.25 K1 = -0.153125 )
      QI2 =(L = 0.3 K1 = -0.16 )
      QI3 =(L = 0.3 K1 = 0.1111854 )
      QK20 =(L = 0.25 K1 =-4.44407251E-3 ROTATE = 45 DEG )
      QK30 =(L = 0.25 K1 = 6.69379023E-3 ROTATE = 45 DEG )
      QC30 =(L = 0.3 K1 = 0.0887209032 )
      QC40 =(L = 0.3 K1 = -0.0925075096 )
      QK40 =(L = 0.25 K1 =-2.71839994E-3 ROTATE = 45 DEG )
      QV50 =(L = 0.8 K1 = 0.3144634253 )
      QK50 =(L = 0.25 K1 = -0.0118827923 ROTATE = 45 DEG )
      QV40 =(L = 0.8 K1 = -0.2315107733 )
      QK60 =(L = 0.25 K1 = 0.0181630136 ROTATE = 45 DEG )
      QV20 =(L = 0.8 K1 = -0.3338947537 )
      QK70 =(L = 0.25 K1 = 0.0187823605 ROTATE = 45 DEG )
      QV10 =(L = 0.8 K1 = 0.1758661022 )
      QC50 =(L = 0.3 K1 = -0.0534188781 )
      QC60 =(L = 0.3 K1 = 0.0462552969 )
      QS1 =(L = 0.3 K1 = -0.0726736057 )
      QS2 =(L = 0.3 K1 = 0.1181799931 )
      QD =(L = 0.28 K1 = -0.1428081577 )
      QF =(L = 0.28 K1 = 0.1430005758 )
      QWOS =(L = 0.3 K1 = 0.130635928 )
      QW1S =(L = 0.3 K1 = -0.0941623338 )
      QW2S =(L = 0.3 K1 = 0.147144593 )
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      QW4S =(L = 0.3 K1 = 0.101658325 )
      QW5S =(L = 0.3 K1 = -0.0390587342 )
      QW6S =(L = 0.3 K1 = 0.045715255 )
      QW7S =(L = 0.3 K1 = -0.0624401604 )
      QW8S =(L = 0.3 K1 = 0.0578542589 )
      QR3S =(L = 0.4 K1 = 0.0700602753 )
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      QROS =(L = 0.4 K1 = -0.0789682959 )
      QX2 =(L = 0.4 K1 = -0.1365377635 )
      QX3 =(L = 0.4 K1 = 0.1855587946 )
      QX1 =(L = 0.4 K1 = 0.1204384663 )
      QX0 =(L = 0.28 K1 = -0.0628410299 )
      QRF =(L = 0.28 K1 = 0.0821733686 )
      QRD =(L = 0.28 K1 = -0.0894435084 )
      QMOL =(L = 0.4 K1 = -0.0904326252 )
      QM1L =(L = 0.4 K1 = 0.0784014557 )

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QM2L  =(L = 0.4 K1 = -0.0308731068 )
QM3L  =(L = 0.4 K1 = 0.0397813418 )
QM4L  =(L = 0.4 K1 = -0.1431479445 )
QM5L  =(L = 0.4 K1 = 0.1483494539 )
QW0L  =(L = 0.3 K1 = 0.1299758268 )
QW1L  =(L = 0.3 K1 = -0.0936577092 )
QW2L  =(L = 0.3 K1 = 0.1467989361 )
QW3L  =(L = 0.3 K1 = -0.1129739732 )
QW4L  =(L = 0.3 K1 = 0.1082998666 )
QW5L  =(L = 0.3 K1 = -0.0523648958 )
QW6L  =(L = 0.3 K1 = 0.0468866148 )
QW7L  =(L = 0.3 K1 = -0.0688458551 )
QW8L  =(L = 0.3 K1 = 0.0587382935 )
QC6I  =(L = 0.3 K1 = 0.1559687833 )
QC5I  =(L = 0.3 K1 = -0.0999897709 )
QV1I  =(L = 0.8 K1 = 0.0665039284 )
QK7I  =(L = 0.25 K1 = -7.89681792E-3 ROTATE = 45 DEG )
QV2I  =(L = 0.8 K1 = 0.1058289248 )
QK6I  =(L = 0.25 K1 = 0.0725188467 ROTATE = 45 DEG )
QV4I  =(L = 0.8 K1 = -0.2083964271 )
QK5I  =(L = 0.25 K1 = -0.118942244 ROTATE = 45 DEG )
QV5I  =(L = 0.8 K1 = 0.0761306339 )
QK4I  =(L = 0.25 K1 = 0.0451267149 ROTATE = 45 DEG )
QC4I  =(L = 0.3 K1 = -0.0526480764 )
QC3I  =(L = 0.3 K1 = -0.0109986446 )
QK3I  =(L = 0.25 K1 = 7.13171367E-7 ROTATE = 45 DEG )
QK2I  =(L = 0.25 K1 = -4.89554434E-3 ROTATE = 45 DEG )

;
SEXT SD1  =(L = 0.5 K2 = -8.2418673226 )
SD2  =(L = 0.5 K2 = -4.0450843401 )
SF1  =(L = 0.3 K2 = 4.4964712253 )
SF2  =(L = 0.3 K2 = 4.6214512465 )
SD3  =(L = 0.5 K2 = -7.9842417299 )
SF3  =(L = 0.3 K2 = 4.5428226582 )
SD4  =(L = 0.5 K2 = -11.9689016618 )
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SD8  =(L = 0.5 K2 = -11.7363409097 )
SF7  =(L = 0.3 K2 = 5.5662268908 )
SD7  =(L = 0.5 K2 = -11.6116828601 )
SF8  =(L = 0.3 K2 = 6.8146774822 )
SD5  =(L = 0.5 K2 = -10.8012137209 )
SF6  =(L = 0.3 K2 = 6.4632214196 )
SF5  =(L = 0.3 K2 = 2.9260404425 )

;
SOL ESOL20 =(BZ = 1 BOUND = 1 GEO = 1 )
ESOL10 =(BZ = 1 DX = 4.59937799E-3 DY = -3.83974478E-5
DZ = 2.12482689E-5 BOUND = 1 CHI1 = -0.0146798078
CHI2 = 8.61644952E-5 CHI3 = 6.95424915E-5 )
ESOL1 =(BZ = 1 DX = -4.59937799E-3 DY = -3.83974478E-5
DZ = 2.12482689E-5 BOUND = 1 CHI1 = 0.0146798079
CHI2 = 8.61552141E-5 CHI3 = 1.26464311E-6 )
ESOL2 =(BZ = 1 BOUND = 1 GEO = 1 )

;
MARK IP =(ALPHAX = -2.0897887E-7 BETAX = 1.0000075814
ALPHAY = -6.18798856E-6 BETAY = 0.0100000348
EX = 2.7237963E-10 EPX = -7.5696116E-10 EY = 2.25753E-12
EPY = -2.05079271E-8 R1 = 8.64399206E-9 R2 = -1.5656983E-10
R3 = 3.5850229E-10 R4 = -6.68715667E-8 DX = -9.446422E-17
DPX = 2.2505462E-17 DY = 9.4346128E-17 DPY = -1.527861E-14
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
CELLF =(ALPHAX = -7.33986639E-3 BETAX = 17.2888862028
PSIX = 33.7991354252 ALPHAY = 6.99574725E-3
BETAY = 3.0478062389 PSIX = 33.70235238
EX = 0.5241971602 EPX = 1.85663761E-3 EY = 5.81831014E-9
EPY = 4.46102264E-9 R1 = 1.52472678E-8 R2 = 3.08047811E-7
R3 = 6.66691104E-9 R4 = 9.93160033E-8 DX = 3.5219713E-16
DPX = 1.1867133E-17 DY = -3.229193E-15 DPY = 1.2502503E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 GEO = 1 )
WSYM =(ALPHAX = -7.54304379E-6 BETAX = 39.3964753597
PSIX = 40.1209089649 ALPHAY = 6.31118758E-6
BETAY = 26.9083607596 PSIX = 39.2503886832
EX = 0.7999999939 EPX = 6.3796455E-11 EY = -1.44237551E-8
EPY = 1.54141801E-9 R1 = -4.57606593E-9 R2 = 1.14803907E-7
R3 = 1.939008E-9 R4 = 6.92350065E-8 DX = 5.4305828E-16
DPX = 7.2360675E-18 DY = -7.8312537E-15 DPY = -2.097957E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
TSYM =(ALPHAX = 4.55633019E-6 BETAX = 1.4996015928
PSIX = 78.8747648708 ALPHAY = 4.47882557E-6
BETAY = 16.2508374858 PSIX = 76.2681950196
EX = -4.5595872E-10 EPX = 0.102428595 EY = 4.70163085E-9
EPY = -8.5018139E-10 R1 = -1.66914981E-7 R2 = 1.08077924E-7
R3 = 1.27752525E-8 R4 = -5.04024934E-9 DX = 1.0065646E-16
DPX = -4.3151091E-17 DY = -1.9641813E-15 DPY = -4.4555629E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
CELLR =(ALPHAX = -5.26827417E-6 BETAX = 23.6062680551
PSIX = 83.6487368393 ALPHAY = -5.35025447E-6
BETAY = 5.9705266625 PSIX = 77.9236140734
EX = -3.68637599E-9 EPX = -1.3916713E-10 EY = -2.95115229E-9
EPY = 6.907933E-10 R1 = 1.13050329E-8 R2 = 7.81968301E-7
R3 = 1.95041327E-9 R4 = 8.71940587E-8 DX = 2.8082981E-16
DPX = 1.6216299E-17 DY = -4.2724826E-15 DPY = 2.6081851E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )

;
LINE WIG =(LWO BW1 LW BW2 LW BW3 LW BW2 LW BW4 LWO)
WIGL =(LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW4 LWO)

;
LINE LSD =(LXSD SD SD LXSD) LSF=(LXSF SF SF LXSF)
LSD1 =(LXSD SD1 LXSD) LSD2=(LXSD SD2 LXSD)
LSD3 =(LXSD SD3 LXSD) LSD4=(LXSD SD4 LXSD)

```

```

LSD5 =(LXSD SD5 LXSD) LSD6=(LXSD SD6 LXSD)
LSD7 =(LXSD SD7 LXSD) LSD8=(LXSD SD8 LXSD)
LSF1 =(LXSF SF1 LXSF) LSF2=(LXSF SF2 LXSF)
LSF3 =(LXSF SF3 LXSF) LSF4=(LXSF SF4 LXSF)
LSF5 =(LXSF SF5 LXSF) LSF6=(LXSF SF6 LXSF)
LSF7 =(LXSF SF7 LXSF) LSF8=(LXSF SF8 LXSF)
TRANS4=( BT1 LX1 QX2 QX2
          LX2 QX3 QX3 LX3)
TRANS4H=( BT2 LX1 QX2 QX2
           LX2 QX3 QX3 LX3)
;
LINE SUPPO=(
  QF L2 B LSD1 QD QD
  L1 B LXS2 QS2
  QS2
  QS1 LS1 B )
SUPPI=(
  QF L2 B LSD5 QD QD
  L1 B LXS2 QS2
  QS2
  QS1 LS1 B )
SUPPIS=(
  QF L2 B LSD4 QD QD
  L1 B LXS2 QS2
  QS2
  QS1 LS1 B )
SUPPIL=(
  QF L2 B LSD8 QD QD
  L1 B LXS2 QS2
  QS2
  QS1 LS1 B );
LINE CELL =(QF LXS2 B L1 QD QD LXS1 B L2 QF)
CELLA =(QF L2 B LXS1 QD QD L1 B LXS2 QF)
CELLSD1=(QF LXS2 B L1 QD QD LSD1 B L2 QF)
CELLSD2=(QF LXS2 B L1 QD QD LSD2 B L2 QF)
CELLSD3=(QF L2 B LSD3 QD QD L1 B LXS2 QF)
CELLSD4=(QF L2 B LSD4 QD QD L1 B LXS2 QF)
CELLSD5=(QF LXS2 B L1 QD QD LSD5 B L2 QF)
CELLSD6=(QF LXS2 B L1 QD QD LSD6 B L2 QF)
CELLSD7=(QF L2 B LSD7 QD QD L1 B LXS2 QF)
CELLSD8=(QF L2 B LSD8 QD QD L1 B LXS2 QF)
CELLSF1=(QF LSF1 B L1 QD QD LXS1 B L2 QF)
CELLSF2=(QF LSF2 B L1 QD QD LXS1 B L2 QF)
CELLSF3=(QF L2 B LXS1 QD QD L1 B LSF3 QF)
CELLSF4=(QF L2 B LXS1 QD QD L1 B LSF4 QF)
CELLSF5=(QF LSF5 B L1 QD QD LXS1 B L2 QF)
CELLSF6=(QF LSF6 B L1 QD QD LXS1 B L2 QF)
CELLSF7=(QF L2 B LXS1 QD QD L1 B LSF7 QF)
CELLSF8=(QF L2 B LXS1 QD QD L1 B LSF8 QF)
CELLS21=(QF LSF2 B L1 QD QD LSD1 B L2 QF)
CELLS33=(QF L2 B LSD3 QD QD L1 B LSF3 QF)
CELLS44=(QF L2 B LSD4 QD QD L1 B LSF4 QF)
CELLS65=(QF LSF6 B L1 QD QD LSD5 B L2 QF)
CELLS77=(QF L2 B LSD7 QD QD L1 B LSF7 QF)
CELLS88=(QF L2 B LSD8 QD QD L1 B LSF8 QF)
CELLM=(CELLF CELL) COIM=(CELLF COL) RFM=(CELLF RF)
RFMS=(CELLF RFS) RFML=(CELLF RFL)
WIGINSH=(QF LXS2 B L1 QD QD LXS1 B LXW4 QW0S QW0S
          LXW1 B LXW2 QW1S QW1S LXW3 B LXW4 QW2S QW2S
          LXW1 B LXW2 QW3S QW3S LXW3 B LXW4 QW4S QW4S
          LXW1 B LXW2 QW5S QW5S LXW0S WIG
          QW6S QW6S WIGL QW7S QW7S WIGL QW8S)
WIGINS =(CELLF WIGINSH WSYM
          QW8S WIGL QW7S QW7S WIGL QW6S QW6S WIG LXW0S
          QW5S QW5S LXW2 B LXW1
          QW4S QW4S LXW4 B LXW3 QW3S QW3S LXW2 B LXW1
          QW2S QW2S LXW4 B LXW3 QW1S QW1S LXW2 B LXW1
          QW0S QW0S LXW4 B LSD3 QD QD L1 B LXS2 QF)
WIGINSHA=(QF LXS2 B L1 QD QD LSD7 B LXW4 QW0L QW0L
           LXW1 B LXW2 QW1L QW1L LXW3 B LXW4 QW2L QW2L
           LXW1 B LXW2 QW3L QW3L LXW3 B LXW4 QW4L QW4L
           LXW1 B LXW2 QW5L QW5L LXW0L WIG
           QW6L QW6L WIGL QW7L QW7L WIGL QW8L)
WIGINSA=(WIGINSHA
          QW8L WIGL QW7L QW7L WIGL QW6L
          QW6L WIG LXW0L QW5L QW5L LXW2 B LXW1
          QW4L QW4L LXW4 B LXW3 QW3L QW3L LXW2 B LXW1
          QW2L QW2L LXW4 B LXW3 QW1L QW1L LXW2 B LXW1
          QW0L QW0L LXW4 B LXS1 QD QD L1 B LXS2 QF)
WIGINSHS=(QF LSF B L1 QD QD LSD B LXW4 QW0S QW0S
           LXW1 B LXW2 QW1S QW1S LXW3 B LXW4 QW2S QW2S
           LXW1 B LXW2 QW3S QW3S LXW3 B LXW4 QW4S QW4S
           LXW1 B LXW2 QW5S QW5S LXW0S WIG
           QW6S QW6S WIGL QW7S QW7S WIGL QW8S)
WIGINSHL=(QF LSF B L1 QD QD LSD B LXW4 QW0L QW0L
           LXW1 B LXW2 QW1L QW1L LXW3 B LXW4 QW2L QW2L
           LXW1 B LXW2 QW3L QW3L LXW3 B LXW4 QW4L QW4L
           LXW1 B LXW2 QW5L QW5L LXW0L WIG
           QW6L QW6L WIGL QW7L QW7L WIGL QW8L)
WIGMS=(CELLF WIGINSHS WSYM)
WIGML=(CELLF WIGINSHL WSYM)
ASCH=(IP -COLO CELL CELLSD1 CELLSD2 CELL CELLSD2 CELLSD1
        CELL CELSD1 CELLSF1 CELL CELLSF1 CELLSF2
        CELL CELLS21 CELL CELSD1 WIGINS
        CELLA CELLS33
        CELLA CELLSF3 CELLSD4 CELLA CELLS44 CELLA CELLSF4
        CELLSD3 CELLA CELLS33 CELLA CELLSF3 CELLSD4 CELLA
        RFS)
ASCHA=(IP -COLI CELL CELLSD5 CELLSF5 CELL CELLSF5 CELLSD5
        CELL CELSD5 CELLSF5 CELL CELLSF5 CELLSF6

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CELL CELLS65 CELL CELLSD5 -WIGINSA
CELLA CELLS77
CELLA CELLSF7 CELLSD8 CELLA CELLS88 CELLA CELLSF8
CELLSD7 CELLA CELLS77 CELLA CELLSF7 CELLSD8 CELLA
RFL)
ASC=(ASCH -ASCHA);
LINE COLO=(
SUPPO LX0 QC60 QC60 LX0
LC50 QC50 QC50 LX0
BH40 LV00 QV10 LV10 QK70 LX0 QV20 LV20
QK60 LX0 QV40 LV40
QK50 LX0 QV50 LV50 BH20
LX0 QK40 LX0 QC40 QC40
LC40 QC30 QC30 LX0 QK30 LX0 BH10
LC30 QK20 LX0 QI3 QI3 LI3
VB30 LX0 BSEP0 LX0 BQ20 QI2 QI2 BQ20
LI2 BQ10 QI1 BQ10 LI1
ESOL10 BS40 BS30 BS20 BS10 LXS ESOL20);
LINE COLI=(
SUPPI LX0 QC6I QC6I LX0
LC5I QC5I QC5I LX0
BH4I LV0I QV1I LV1I QK7I LX0 QV2I LV2I
QK6I LX0 QV4I LV4I
QK5I LX0 QV5I LV5I BH2I
LX0 QK4I LX0 QC4I QC4I
LC4I QC3I QC3I LX0 QK3I LX0 VB2I
LC3I QK2I LX0 QI3 QI3 LI3
VB3I LSEP QI2 QI2
LI2 QI1 QI1 LI1
ESOL1 BS4I BS3I BS2I BS1I LXS ESOL2 );
LINE ACC =(LRF CAV LRF)
RFC =(QRF ACC QRD QRD ACC QRF)
RFCM=(CELLR RFC);
LINE RFS=(
SUPPIS LX0 QR3S QR3S LR3S
QR2S QR2S LR2S QR1S LR1S QRO5 QRO5
LX0 TRANS4 TSYM -TRANS4H LX0 QX1 QX1 ACC
QX0 QX0 ACC QRF CELLR);
LINE RFL=(
SUPPIL LX0
QM5L QM5L LM5L QM4L QM4L LM4L QM3L QM3L LM3L
QM2L QM2L LM2L QM1L QM1L ACC QM0L QM0L ACC
QRF CELLR 4*RFC);
CAVI CAV=(VOLT= 3.0293 MV FREQ=500 MHZ)
;
FFS USE=ASC;
FREE QM*
FIT CELLR BX @ 1 BY @ 1 AX 0 1 AY 0 1
FIT BX 1 1 BY .01 1 AX 0 1 AY 0 1 GX 0 1
FIT NX 26.12 1 NY 25.15 1
END
STOP

```

1- 28/08/90 103021233 MEMBER NAME \SADIN2 *.FORT SAD -- 00000000
 13.5 GEV COLLIDER FOR THE KEK B FACTORY HEAD ON (\LR102A)
 MOMENTUM= 3.5 GEV;
 OFF ECHO;OFF EMIT COD CTIME RAD RFSW;

LER (head-on)

```

;
DRIFT LXS =(L = 0.3 ) LI1 =(L = 0.4 ) LIS =(L = 1.7 )
      LI2 =(L = 2.1 ) LX0 =(L = 0.2 )
      LC30 =(L = 2.4374817866 ) LC40 =(L = 9.2082000173 )
      LC50 =(L = 1.2 ) LH50 =(L = 3.6112151195 )
      LH20 =(L = 5.8353269184 ) LHBO =(L = 5.6629389352 )
      LH10 =(L = 11.1947998334 ) LC60 =(L = 5.2803882349 )
      LB =(L = 1.7 ) LS1 =(L = 2.4646142009 )
      LS2 =(L = 5.6949239224 ) L2 =(L = 1.745 )
      L1 =(L = 0.95 ) LXSD =(L = 0.53 ) LXSF =(L = 1.395 )
      L2W =(L = 1.725 ) L1W =(L = 0.93 )
      L1WS =(L = 1.72 ) LW0 =(L = 0.2 ) LW =(L = 0.3 )
      LM5S =(L = 3.4871843211 ) LM4S =(L = 4.0935341281 )
      LM3S =(L = 3.8289115583 ) LM2S =(L = 3.8898630677 )
      LRF =(L = 3.05 ) LX1 =(L = 2.6767340731 )
      LX2 =(L = 2.4169002935 ) LX3 =(L = 0.2 )
      LBV1 =(L = 1.445 ) LBV2 =(L = 2 )
      LR1L =(L = 1.8592330142 ) LR2L =(L = 8.453552459 )
      LR3L =(L = 4.5704076703 ) L1WL =(L = 1.82 )
      LC6I =(L = 10.9080313441 ) LBH4I =(L = 0.2 )
      LH1I =(L = 13.2527183953 ) LBH3I =(L = 3.3073722916 )
      LH2I =(L = 3.4495523456 ) LH5I =(L = 3.9562066599 )
      LC5I =(L = 5.1779300568 ) LC4I =(L = 3.4972813602 )
      LC3I =(L = 8.8812583918 ) LX30 =(L = 0.3 )
      LI2I =(L = 4 )
;
BEND BS10 =(L = 0.2 ANGLE = 3.1E-3 )
      BS20 =(L = 0.2 ANGLE = 7.87E-3 )
      BS30 =(L = 0.2 ANGLE = 0.01075 )
      BS40 =(L = 0.2 ANGLE = 0.01183 )
      BQ10 =(ANGLE = 6.69E-3 )
      BSEPO =(L = 0.7 ANGLE = 0.028 E1 = 0.014 E2 = 0.014 )
      VB20 =(L = 0.4 ANGLE = -4.50232494E-4 ROTATE = 90 DEG )
      BH10 =(L = 5 ANGLE = -0.066 E1 = -0.033 E2 = -0.033 )
      BH20 =(L = 4 ANGLE = 0.0384144909 E1 = 0.0192072455
      E2 = 0.0192072455 )
      VB30 =(L = 0.4 ANGLE = 0 ROTATE = 90 DEG )
      VB40 =(L = 0.4 ANGLE = 0 ROTATE = 90 DEG )
      BH40 =(L = 2 ANGLE = -0.0267662416 E1 = -0.0133831208
      E2 = -0.0133831208 )
      BCELL =(L = 0.27 ANGLE = 0.0186999563 E1 = 9.349978E-3
      E2 = 9.349978E-3 )
      BW1 =(L = 0.25 ANGLE = 0 )
      BW2 =(L = 0.5 ANGLE = 0 )
      BW3 =(L = 0.5 ANGLE = 0 )
      BW4 =(L = 0.25 ANGLE = 0 )
      BT2 =(L = 1 ANGLE = -0.0525 E1 = -0.02625
      E2 = -0.02625 )
      BV1 =(L = 3.18 ANGLE = 0.02162 E2 = 0.02162
      ROTATE = 90 DEG )
      BV2 =(L = 3.18 ANGLE = -0.02162 E1 = -0.02162
      ROTATE = 90 DEG )
      BT1 =(L = 1 ANGLE = 0.0525 E1 = 0.02625 E2 = 0.02625 )
      BH4I =(L = 2.4 ANGLE = 5.00546374E-3 E1 = 2.50273187E-3
      E2 = 2.50273187E-3 )
      BH2I =(L = 5 ANGLE = 5.46628242E-3 E1 = 2.73314121E-3
      E2 = 2.73314121E-3 )
      VB3I =(L = 0.4 ANGLE = -1.97568217E-7 ROTATE = 90 DEG )
      VB2I =(L = 0.4 ANGLE = -4.49651187E-4 ROTATE = 90 DEG )
      BNDL =(L = 0.2 ANGLE = 2.5E-3 E1 = 1.25E-3 E2 = 1.25E-3 )
      BS4I =(L = 0.2 ANGLE = -0.01183 )
      BS3I =(L = 0.2 ANGLE = -0.01075 )
      BS2I =(L = 0.2 ANGLE = -7.87E-3 )
      BS1I =(L = 0.2 ANGLE = -3.1E-3 )
;
QUAD QI1 =(L = 0.25 K1 = -0.35 )
      QI2 =(L = 0.15 K1 = 0.1133587 )
      QK20 =(L = 0.2 K1 = 8.9202901E-4 ROTATE = 45 DEG )
      QK30 =(L = 0.2 K1 = 4.61641526E-3 ROTATE = 45 DEG )
      QC30 =(L = 0.2 K1 = -0.0699059394 )
      QK40 =(L = 0.2 K1 = -0.0300286611 ROTATE = 45 DEG )
      QC40 =(L = 0.2 K1 = 0.1258367742 )
      QH60 =(L = 0.2 K1 = -0.091177462 )
      QK60 =(L = 0.2 K1 = 0.0691849607 ROTATE = 45 DEG )
      QH50 =(L = 0.2 K1 = 1.62483025E-3 )
      QK70 =(L = 0.2 K1 = -0.0827116179 ROTATE = 45 DEG )
      QH20 =(L = 0.2 K1 = 0.0405389177 )
      QK80 =(L = 0.2 K1 = 1.89640759E-3 ROTATE = 45 DEG )
      QH10 =(L = 0.2 K1 = 0.1010935615 )
      QC50 =(L = 0.2 K1 = -0.1160269576 )
      QC60 =(L = 0.2 K1 = 0.1238185943 )
      QS1 =(L = 0.2 K1 = -0.0790087037 )
      QS2 =(L = 0.2 K1 = 0.1294065624 )
      QD =(L = 0.1 K1 = -0.1380902676 )
      QF =(L = 0.1 K1 = 0.1392771557 )
      QW0S =(L = 0.12 K1 = 0.1313836333 )
      QW1S =(L = 0.12 K1 = -0.098733284 )
      QW2S =(L = 0.12 K1 = 0.1423014363 )
      QW3S =(L = 0.12 K1 = -0.1056825656 )
      QW4S =(L = 0.12 K1 = 0.0650961732 )
      QW5S =(L = 0.12 K1 = -0.0447715288 )
      QW6S =(L = 0.12 K1 = 0.0704228612 )
      QW7S =(L = 0.12 K1 = -0.0509949903 )
      QW8S =(L = 0.12 K1 = 0.0166175836 )
      QM5S =(L = 0.2 K1 = 0.1860000778 )
      QM4S =(L = 0.2 K1 = -0.1491781033 )

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QM3S  =(L = 0.2 K1 = 0.216898679 )
QM2S  =(L = 0.2 K1 = -0.1009723551 )
QM1S  =(L = 0.2 K1 = 0.1616223485 )
QM0S  =(L = 0.15 K1 = -0.0966680807 )
QRF   =(L = 0.15 K1 = 0.093312569 )
QRD   =(L = 0.15 K1 = -0.093312569 )
QX0   =(L = 0.15 K1 = -0.0650843366 )
QX1   =(L = 0.15 K1 = 0.1797043328 )
QX2   =(L = 0.15 K1 = -0.1681907131 )
QX3   =(L = 0.15 K1 = 0.1690472397 )
QR0L  =(L = 0.15 K1 = 2.8587607E-3 )
QR1L  =(L = 0.2 K1 = 0.1321341209 )
QR2L  =(L = 0.2 K1 = -0.1183629733 )
QR3L  =(L = 0.2 K1 = 0.1338412058 )
QW0L  =(L = 0.12 K1 = 0.1286682211 )
QW1L  =(L = 0.12 K1 = -0.1003036539 )
QW2L  =(L = 0.12 K1 = 0.143374166 )
QW3L  =(L = 0.12 K1 = -0.1097429542 )
QW4L  =(L = 0.12 K1 = 0.0823042698 )
QW5L  =(L = 0.12 K1 = -0.042347718 )
QW6L  =(L = 0.12 K1 = 0.0601027884 )
QW7L  =(L = 0.12 K1 = -0.0505283748 )
QW8L  =(L = 0.12 K1 = 0.0257991707 )
QC6I  =(L = 0.2 K1 = 0.0552603905 )
QCS1  =(L = 0.2 K1 = -0.0991427427 )
QH1I  =(L = 0.2 K1 = 0.1324116875 )
QK8I  =(L = 0.2 K1 = 6.97414024E-3 ROTATE = 45 DEG )
QH2I  =(L = 0.2 K1 = 0.1161805883 )
QK7I  =(L = 0.2 K1 = -0.0249764077 ROTATE = 45 DEG )
QH5I  =(L = 0.2 K1 = -0.0448078357 )
QK6I  =(L = 0.2 K1 = 0.0455007491 ROTATE = 45 DEG )
QH6I  =(L = 0.2 K1 = -0.0588127585 )
QC4I  =(L = 0.2 K1 = 0.123131492 )
QK4I  =(L = 0.2 K1 = 0.0354727887 ROTATE = 45 DEG )
QC3I  =(L = 0.2 K1 = -0.0992346244 )
QK3I  =(L = 0.2 K1 = -0.0308140756 ROTATE = 45 DEG )
QK2I  =(L = 0.2 K1 = 0.0208699027 ROTATE = 45 DEG )

;
SEXT SD1  =(L = 0.22 K2 = -12.9957734259 )
      SD2  =(L = 0.22 K2 = -4.3226309205 )
      SD1A =(L = 0.22 K2 = -12.435645485 )
      SF1  =(L = 0.15 K2 = 3.0611967444 )
      SF2  =(L = 0.15 K2 = 3.2460624313 )
      SD1B =(L = 0.22 K2 = -9.2455007479 )
      SD3  =(L = 0.22 K2 = -6.5643549242 )
      SF3  =(L = 0.15 K2 = 3.9570011682 )
      SD4A =(L = 0.22 K2 = -12.3642629302 )
      SF4  =(L = 0.15 K2 = 6.1117448211 )
      SD3A =(L = 0.22 K2 = -8.0654182858 )
      SF3A =(L = 0.15 K2 = 1.6300376016 )
      SD4  =(L = 0.22 K2 = -11.6231306467 )
      SD8  =(L = 0.22 K2 = -11.7306020365 )
      SF7A =(L = 0.15 K2 = 2.8647346843 )
      SD7A =(L = 0.22 K2 = -5.3728532822 )
      SF8  =(L = 0.15 K2 = 7.3738848197 )
      SD8A =(L = 0.22 K2 = -12.9112296943 )
      SF7  =(L = 0.15 K2 = 4.4570159255 )
      SD7  =(L = 0.22 K2 = -10.7337576016 )
      SD5B =(L = 0.22 K2 = -4.5749984292 )
      SF6  =(L = 0.15 K2 = 8.9193128899 )
      SF5  =(L = 0.15 K2 = 4.0212069215 )
      SD5A =(L = 0.22 K2 = -5.0062141488 )
      SD6  =(L = 0.22 K2 = -3.0079285296 )
      SD5  =(L = 0.22 K2 = -7.5496195265 )

;
SOL ESOL20 =(BZ = 1 BOUND = 1 GEO = 1 )
     ESOL10 =(BZ = 1 DX = -0.0105127371 DY = 2.00665053E-4
           DZ = 1.11031454E-4 BOUND = 1 CHI1 = 0.0335477018
           CHI2 = -4.49847337E-4 CHI3 = 1.86240214E-5 )
     ESOL11 =(BZ = 1 DX = 0.0105127371 DY = 2.00665053E-4
           DZ = 1.11031454E-4 BOUND = 1 CHI1 = -0.0335477046
           CHI2 = -4.49631899E-4 CHI3 = 1.39658099E-5 )
     ESOL21 =(BZ = 1 BOUND = 1 GEO = 1 )

;
MARK IP  =(ALPHAX = -9.49585989E-7 BETAX = 1.0000006632
          ALPHAY = -4.83225474E-7 BETAY = 0.0100000107
          EX = 5.27669985E-5 EPX = 1.66005796E-5 EY = 6.92375066E-7
          EPY = 1.57505342E-4 R1 = 2.10456345E-9 R2 = -1.77244734E-9
          R3 = 2.02647592E-7 R4 = 2.55176107E-7 DX = -2.4583317E-17
          DPX = 1.2521507E-17 DY = -8.7084307E-17 DPY = 1.5880153E-14
          EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 8E-4 )
      CELLF =(ALPHAX = -5.37743232E-7 BETAX = 17.3752285904
            PSIX = 33.7074344524 ALPHAY = -1.0378179E-6
            BETAY = 3.029057083 PSIY = 33.736709016 EX = 0.4966708772
            EPX = -1.21392108E-5 EY = 1.18491765E-5 EPY = -9.07817866E-6
            R1 = 1.17169999E-8 R2 = -1.05269731E-7 R3 = 3.01846599E-9
            R4 = 7.47348473E-8 DX = 1.031978E-16 DPX = 2.5657391E-18
            DY = 2.9645631E-15 DPY = -2.8859459E-16 EMIX = 1.85E-8
            EMIY = 1.85E-10 DP = 8E-4 GEO = 1 )
      WSYM =(ALPHAX = 2.06002581E-6 BETAX = 11.7151770046
            PSIX = 39.9906197622 ALPHAY = 3.74767392E-6
            BETAY = 38.8314994676 PSIY = 39.2344919157
            EX = 0.499923506 EPX = -1.47839832E-5 EY = 9.96195393E-5
            EPY = -1.02015149E-6 R1 = 7.93567011E-9 R2 = -6.89458135E-7
            R3 = 1.6563293E-9 R4 = 6.48358496E-9 DX = 8.473827E-17
            DPX = 3.1246452E-18 DY = 9.7187532E-15 DPY = 1.3629095E-16
            EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 8E-4 )
      CELLR =(ALPHAX = 1.24584219E-6 BETAX = 21.2711538987
            PSIX = 80.8431367751 ALPHAY = -3.586724E-6
            BETAY = 5.5732361018 PSIY = 74.8271532032

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EX = 1.05827077E-4 EPX = 1.09138537E-5 EY = -6.34616829E-6
EY = 7.1985134E-6 R1 = 1.6649472E-8 R2 = -7.33084623E-8
R3 = 1.34842074E-9 R4 = 6.57420638E-8 DX = -1.1475748E-16
DPX = -2.255322E-18 DY = -3.6034316E-15 DPY = 3.8448398E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 8E-4 )
TSYM = (ALPHAX = 4.15770594E-6 BETAX = 11.8287406005
PSIX = 90.4645634609 ALPHAY = -1.53937119E-6
BETAY = 11.9677414723 PSIY = 81.7384746406
EX = -1.11223781E-4 EPX = 0.0472397808 EY = -0.0999910465
EY = 4.42984101E-6 R1 = -3.72886343E-8 R2 = -8.59400289E-8
R3 = 8.4239068E-11 R4 = -3.18108135E-8 DX = 9.0916987E-17
DPX = 1.5525283E-18 DY = -2.4272882E-15 DPY = 4.7157485E-16
EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 8E-4 )
;
;
LINE B = (BCELL LB BCELL)
;
LINE WIG3 = ( LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW
              BW2 LW BW4 LWO )
WIG4 = ( LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW3 LW
              BW2 LW BW4 LWO )
WIG5 = ( LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW3 LW
              BW2 LW BW3 LW BW2 LW BW4 LWO )
;
LINE LSD = (LX0 SD SD LXSD) LSD1A = (LXSD SD1 LX0)
LSD1 = (LX0 SD1 LXSD) LSD2 = (LX0 SD2 LXSD)
LSD1A = (LX0 SD1A LXSD) LSD1B = (LX0 SD1B LXSD)
LSD3 = (LX0 SD3 LXSD) LSD4 = (LX0 SD4 LXSD)
LSD3A = (LX0 SD3A LXSD) LSD4A = (LX0 SD4A LXSD)
LSD5 = (LX0 SD5 LXSD) LSD6 = (LX0 SD6 LXSD)
LSD5A = (LX0 SD5A LXSD) LSD5B = (LX0 SD5B LXSD)
LSD7 = (LX0 SD7 LXSD) LSD8 = (LX0 SD8 LXSD)
LSD7A = (LX0 SD7A LXSD) LSD8A = (LX0 SD8A LXSD)
LSF1 = (LX0 SF1 LXS F) LSF2 = (LX0 SF2 LXS F)
LSF3 = (LX0 SF3 LXS F) LSF4 = (LX0 SF4 LXS F)
LSF3A = (LX0 SF3A LXS F)
LSF5 = (LX0 SF5 LXS F) LSF6 = (LX0 SF6 LXS F)
LSF7 = (LX0 SF7 LXS F) LSF8 = (LX0 SF8 LXS F)
LSF7A = (LX0 SF7A LXS F)
TRANS4 = ( BT1 LX1 QX2 QX2
            LX2 QX3 QX3 LX3
            BV1 LBV1 BV2 LBV2 )
TRANS4H = ( BT2 LX1 QX2 QX2
            LX2 QX3 QX3 LX3
            BV1 LBV1 BV2 LBV2 )
;
LINE SUPP1 = (
QF L2 B -LSD5 QD QD
L1 B L2 QS2
QS2
QS1 LS1 B )
SUPP1S = (
QF L2 B -LSD1 QD QD
L1 B L2 QS2
QS2
QS1 LS1 B )
SUPP1S = (
QF L2 B L1 QD QD
LSD4 B L2 QS2
QS2
QS1 LS1 B )
SUPP1L = (
QF L2 B L1 QD QD
LSD8 B L2 QS2
QS2
QS1 LS1 B )
SUPPX = (
QF L2 B LSD QD QD
L1 B L2 QS2
QS2
QS1 LS1 B );
LINE CELL = (QF L2 B L1 QD QD LSD1 B L2 QF)
CSD1 = (QF L2 B L1 QD QD LSD1A B L2 QF)
CSD1B = (QF L2 B L1 QD QD LSD1B B L2 QF)
CSD2 = (QF L2 B L1 QD QD LSD2 B L2 QF)
CSD3 = (QF L2 B L1 QD QD LSD3 B L2 QF)
CSD3A = (QF L2 B L1 QD QD LSD3A B L2 QF)
CSD4 = (QF L2 B L1 QD QD LSD4 B L2 QF)
CSD4A = (QF L2 B L1 QD QD LSD4A B L2 QF)
CSF1 = (QF LSF1 B L1 QD QD L1 B L2 QF)
CSF2 = (QF LSF2 B L1 QD QD L1 B L2 QF)
CSF3 = (QF LSF3 B L1 QD QD L1 B L2 QF)
CSF3A = (QF LSF3A B L1 QD QD L1 B L2 QF)
CSF4 = (QF LSF4 B L1 QD QD L1 B L2 QF)
CS21B = (QF LSF2 B L1 QD QD LSD1B B L2 QF)
CS34 = (QF LSF3 B L1 QD QD LSD4 B L2 QF)
CS34A = (QF LSF3 B L1 QD QD LSD4A B L2 QF)
CS34AA = (QF LSF3A B L1 QD QD LSD4 B L2 QF)
CS43 = (QF LSF4 B L1 QD QD LSD3 B L2 QF)
CS43A = (QF LSF4 B L1 QD QD LSD3A B L2 QF)
CSD5 = (QF L2 B L1 QD QD LSD5 B L2 QF)
CSD5A = (QF L2 B L1 QD QD LSD5A B L2 QF)
CSD5B = (QF L2 B L1 QD QD LSD5B B L2 QF)
CSD6 = (QF L2 B L1 QD QD LSD6 B L2 QF)
CSD7 = (QF L2 B L1 QD QD LSD7 B L2 QF)
CSD7A = (QF L2 B L1 QD QD LSD7A B L2 QF)
CSD8 = (QF L2 B L1 QD QD LSD8 B L2 QF)
CSD8A = (QF L2 B L1 QD QD LSD8A B L2 QF)
CSF5 = (QF LSF5 B L1 QD QD L1 B L2 QF)

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CSF6=(QF LSF6 B L1 QD QD L1 B L2 QF)
CSF7=(QF LSF7 B L1 QD QD L1 B L2 QF)
CSF7A=(QF LSF7A B L1 QD QD L1 B L2 QF)
CSF8=(QF LSF8 B L1 QD QD L1 B L2 QF)
CS65B=(QF LSF6 B L1 QD QD LSD5B B L2 QF)
CS78=(QF LSF7 B L1 QD QD LSD8 B L2 QF)
CS78A=(QF LSF7 B L1 QD QD LSD8A B L2 QF)
CS78AA=(QF LSF7A B L1 QD QD LSD8 B L2 QF)
CS87=(QF LSF8 B L1 QD QD LSD7 B L2 QF)
CS87A=(QF LSF8 B L1 QD QD LSD7A B L2 QF)
CELLM=(CELLF CELL) COLM=(CELLF COL) RFMS=(CELLF RFS)
RFML=(CELLF RFL)
WIGINSH=(QF L2 B L1 QD QD L1 B L2W QW0S QW0S
L2W B L1W QW1S QW1S L1W B L2W QW2S QW2S
L2W B L1W QW3S QW3S L1W B L2W QW4S QW4S
L2W B L1WS QW5S QW5S WIG3
QW6S QW6S WIG5 QW7S QW7S WIG5 QW8S)
WIGINS=(CELLF WIGINSH WSYM
QW8S WIG5 QW7S QW7S WIG5 QW6S
QW6S WIG3 QW5S QW5S
L1WS B L2W QW4S QW4S L2W B L1W QW3S QW3S
L1W B L2W
QW2S QW2S L2W B L1W QW1S QW1S L1W B L2W
QW0S QW0S L2W B L1 QD QD LSD3 B L2 QF)
WIGINSHA=(QF L2 B -LSD7 QD QD L1 B L2W QW0L QW0L
L2W B L1W QW1L QW1L L1W B L2W QW2L QW2L
L2W B L1W QW3L QW3L L1W B L2W QW4L QW4L
L2W B L1WL QW5L QW5L WIG4
QW6L QW6L WIG5 QW7L QW7L WIG5 QW8L)
WIGINSA=(WIGINSHA
QW8L WIG5 QW7L QW7L WIG5 QW6L
QW6L WIG4 QW5L QW5L
L1WL B L2W QW4L QW4L L2W B L1W QW3L QW3L
L1W B L2W
QW2L QW2L L2W B L1W QW1L QW1L L1W B L2W
QW0L QW0L L2W B L1 QD QD L1 B L2 QF)
WIGMS=(CELLF WIGINSH WSYM)
WIGML=(CELLF WIGINSHA WSYM)
ASCH=(IP -COLO CELL CSD1 CSD2 CELL CSD2 CSD1A
CELL CSD1A CSF1 CELL CSF1 CSF2
CELL CS21B CELL CSD1B WIGINS
CELL CSD3
CSF3 CELL CS34A CELL CSD4A CSF4 CELL
CS43A CELL CSD3A CSF3A CELL CS34AA CELL
RFS)
ASCHA=(IP -COLI CELL CSD5 CSD6 CELL CSD6 CSD5A
CELL CSD5A CSF5 CELL CSF5 CSF6
CELL CS65B CELL CSD5B -WIGINSA
CELL CSD7
CSF7 CELL CS78A CELL CSD8A CSF8 CELL
CS87A CELL CSD7A CSF7A CELL CS78AA CELL
RFL)
ASC=(ASCH -ASCHA)
;
LINE COLO=(
SUPPO LX0 QC60 QC60 LC60 QC50 QC50 LX0 BH40
LX0 VB40 LX0
LX0 QH10 QH10 LH10 QK80 LX0 QH20 QH20
LH80 LH20 QK70 LX0
QH50 QH50 LH50 QK60 LX0 QH60 QH60
LX0 VB30 LX0 BH20 LC50
QC40 LX0 QK40 LC40 QC30 QC30 LX0 QK30
LX0 BH10 LC30 VB20 LX0 QK20 LX0
QI2 QI2 LI2 BSEPO LIS
BQ10 QI1 QI1 BQ10 LI1
ESOL10 BS40 BS30 BS20 BS10 LXS ESOL20);
LINE COLI=(
SUPPI LX0 QC6I QC6I LC6I QC5I QC5I LBH4I
BH4I LX0 QH1I QH1I LH1I QK8I LX0 QH2I QH2I
LBH3I LH2I QK7I LX0
QH5I QH5I LH5I QK6I LX0 QH6I QH6I
LX0 BH2I LC5I
QC4I LX0 QK4I LC4I QC3I QC3I LX0 QK3I
LX0 VB3I LC3I VB2I LX0 QK2I LX0
QI2 QI2 LX30 BNDL LI2I
QI1 QI1 LI1
ESOL1I BS4I BS3I BS2I BS1I LXS ESOL2I);
LINE ACC=(LRF CAV LRF)
RFC=(QRF ACC QRD QRD ACC QRF)
RFCM=(CELLR RFC);
LINE RFL=(
SUPP1L LX0 QR3L QR3L LR3L
QR2L QR2L LR2L QR1L QR1L LR1L QR0L QR0L
LX0 TRANS4 TSYM -TRANS4H LX0 QX1 QX1 ACC
QX0 QX0 ACC QRF CELLR);
LINE RFS=(
SUPP1S LX0
QM5S QM5S IM5S QM4S QM4S IM4S QM3S QM3S IM3S
QM2S QM2S IM2S QM1S QM1S ACC QM0S QM0S ACC
QRF CELLR 4*RFC);
CAVI CAV=(VOLT= 1.278 MV FREQ=500 MHZ)
;
FFS USE=ASC;
FREE QM*
FIT CELLR BX @ 1 BY @ 1 AX 0 1 AY 0 1
FIT BX 1 1 BY .01 1 GX 0 1 AX 0 1 AY 0 1
FIT NX 27.19 1 NY 25.15 1
END

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1- 28/08/90 103041629 MEMBER NAME \SADIN3 *.FORT SAD --
1 8 GEV COLLIDER FOR THE KEK B FACTORY CRAB CROSSING (\CHRO5)
MOMENTUM= 8 GEV;
OFF ECHO;OFF EMIT COD CTIME RAD RFSW;

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HER (crab-crossing)

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;
DRIFT LXS =(L = 1.1 ) LI1 =(L = 1.1 )
LI2 =(L = 3.9698157506 ) LX0 =(L = 0.2 )
LI3 =(L = 9.5 ) LC3 =(L = 0.4112426319 )
LC4 =(L = 3.4912265631 ) LC5 =(L = 2.4441272849 )
LC6 =(L = 5.1474151012 ) LC7 =(L = 2.1421279561 )
LC8 =(L = 1.9856107827 ) LC9 =(L = 0.1762201917 )
LXC =(L = 3 ) LASO =(L = 2.8493652979 )
LA40 =(L = 2.7303425534 ) LA30 =(L = 2.6356248972 )
LA20 =(L = 2.2356861582 ) LA10 =(L = 2.329919426 )
LS1 =(L = 0.4936511031 ) LS2 =(L = 8.0627478681 )
LXS2 =(L = 0.7 ) LI1 =(L = 0.5 ) LXSD =(L = 0.2 )
L2 =(L = 0.25 ) LXS1 =(L = 0.9 ) LXSF =(L = 0.2 )
LXW4 =(L = 0.23 ) LXW1 =(L = 0.68 ) LXW2 =(L = 0.48 )
LXW3 =(L = 0.88 ) LXWOS =(L = 1.285 )
LW0 =(L = 0.2 ) LW =(L = 0.2 )
LR3S =(L = 5.0524705031 ) LR2S =(L = 2.0275798886 )
LR1S =(L = 2.7549574739 ) LX1 =(L = 0.2 )
LX2 =(L = 2.4962813378 ) LX3 =(L = 5.9930152438 )
LRF =(L = 3 ) LM2L =(L = 3.6793743216 )
LM3L =(L = 2.7303601573 ) LM4L =(L = 2.1737887154 )
LM5L =(L = 2.9354707051 ) LXWOL =(L = 2.985 )
LA1I =(L = 3.4664223319 ) LA2I =(L = 2.3090304327 )
LA3I =(L = 2.7993170931 ) LA4I =(L = 3.679560539 )
LA5I =(L = 3.9266079362 )

;
BEND VB3 =(L = 0.4 ANGLE = -1.88836914E-3 ROTATE = 90 DEG )
VB2 =(L = 0.4 ANGLE = 8.56703422E-4 ROTATE = 90 DEG )
BH2O =(L = 5 ANGLE = -0.0120200439 E1 = -6.01002195E-3
E2 = -6.01002195E-3 )
BH4O =(L = 2.5 ANGLE = -0.0123932601 E1 = -6.19663005E-3
E2 = -6.19663005E-3 )
B =(L = 3.4 ANGLE = 0.0373999126 E1 = 0.018699956
E2 = 0.018699956 )
BW1 =(L = 0.5 ANGLE = 0 )
BW2 =(L = 1 ANGLE = 0 )
BW3 =(L = 1 ANGLE = 0 )
BW4 =(L = 0.5 ANGLE = 0 )
BT1 =(L = 6 ANGLE = -0.064 E1 = -0.032 E2 = -0.032 )
BT2 =(L = 6 ANGLE = 0.064 E1 = 0.032 E2 = 0.032 )
BH4 =(L = 2.5 ANGLE = 0.0123932601 E1 = 6.19663005E-3
E2 = 6.19663005E-3 )
BH2 =(L = 5 ANGLE = 0.0120200439 E1 = 6.01002195E-3
E2 = 6.01002195E-3 )

;
QUAD QC1 =(L = 0.3 K1 = -0.27196926 )
QC2 =(L = 0.3 K1 = 0.1013915361 )
QK2O =(L = 0.25 K1 = 0.011722842 ROTATE = 45 DEG )
QK3O =(L = 0.25 K1 = -0.0460288225 ROTATE = 45 DEG )
QC3 =(L = 0.3 K1 = 9.62331051E-3 )
QK5O =(L = 0.25 K1 = 0.0815687259 ROTATE = 45 DEG )
QC6 =(L = 0.3 K1 = 0.1377920645 )
QK6O =(L = 0.25 K1 = 0.0224331468 ROTATE = 45 DEG )
QC7 =(L = 0.3 K1 = -0.1184208411 )
QK7O =(L = 0.25 K1 = -0.0971659048 ROTATE = 45 DEG )
QK8O =(L = 0.25 K1 = 0.0662605761 ROTATE = 45 DEG )
QC8 =(L = 0.3 K1 = 0.0388150655 )
QA6O =(L = 0.3 K1 = 0.1130790259 )
QA5O =(L = 0.3 K1 = -0.1299532774 )
QA4O =(L = 0.3 K1 = 0.0958186658 )
QA3O =(L = 0.3 K1 = -0.0486937676 )
QA2O =(L = 0.3 K1 = 0.1732556239 )
QA1O =(L = 0.3 K1 = -0.0575588669 )
QS1 =(L = 0.3 K1 = -0.0726736057 )
QS2 =(L = 0.3 K1 = 0.1181799931 )
QD =(L = 0.28 K1 = -0.1428081577 )
QF =(L = 0.28 K1 = 0.1430005758 )
QWOS =(L = 0.3 K1 = 0.130635928 )
QW1S =(L = 0.3 K1 = -0.0941623338 )
QW2S =(L = 0.3 K1 = 0.147144593 )
QW3S =(L = 0.3 K1 = -0.1197096798 )
QW4S =(L = 0.3 K1 = 0.101658325 )
QW5S =(L = 0.3 K1 = -0.0390587342 )
QW6S =(L = 0.3 K1 = 0.045715255 )
QW7S =(L = 0.3 K1 = -0.0624401604 )
QW8S =(L = 0.3 K1 = 0.0578542589 )
QR3S =(L = 0.4 K1 = 0.0651974225 )
QR2S =(L = 0.4 K1 = -0.1733920147 )
QR1S =(L = 0.4 K1 = 0.1758338749 )
QROS =(L = 0.4 K1 = -0.0881417897 )
QX2 =(L = 0.4 K1 = -0.1405527925 )
QX3 =(L = 0.4 K1 = 0.1861445917 )
QX1 =(L = 0.4 K1 = 0.123932937 )
QXO =(L = 0.28 K1 = -0.0711324133 )
QRF =(L = 0.28 K1 = 0.0891465495 )
QRD =(L = 0.28 K1 = -0.0914202755 )
QMOL =(L = 0.4 K1 = -0.0718560926 )
QM1L =(L = 0.4 K1 = 0.066645719 )
QM2L =(L = 0.4 K1 = -0.0274012449 )
QM3L =(L = 0.4 K1 = 0.0650605656 )
QM4L =(L = 0.4 K1 = -0.1134502566 )
QM5L =(L = 0.4 K1 = 0.1150202568 )
QWOL =(L = 0.3 K1 = 0.1299758268 )
QW1L =(L = 0.3 K1 = -0.0936577092 )
QW2L =(L = 0.3 K1 = 0.1467989361 )
QW3L =(L = 0.3 K1 = -0.1129739732 )

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QW4L =(L = 0.3 K1 = 0.1082998666 )
QW5L =(L = 0.3 K1 = -0.0523648958 )
QW6L =(L = 0.3 K1 = 0.0468866148 )
QW7L =(L = 0.3 K1 = -0.0688458551 )
QW8L =(L = 0.3 K1 = 0.0587382935 )
QA1I =(L = 0.3 K1 = -0.0298653995 )
QA2I =(L = 0.3 K1 = 0.1503189608 )
QA3I =(L = 0.3 K1 = -0.0818533384 )
QA4I =(L = 0.3 K1 = 0.0909283312 )
QA5I =(L = 0.3 K1 = -0.0995354715 )
QA6I =(L = 0.3 K1 = 0.0930858022 )
QK8 =(L = 0.25 K1 = -0.0662605761 ROTATE = 45 DEG )
QK7 =(L = 0.25 K1 = 0.0971659048 ROTATE = 45 DEG )
QK6 =(L = 0.25 K1 = -0.0224331468 ROTATE = 45 DEG )
QK5 =(L = 0.25 K1 = -0.0815687259 ROTATE = 45 DEG )
QK3 =(L = 0.25 K1 = 0.0460288225 ROTATE = 45 DEG )
QK2 =(L = 0.25 K1 = -0.011722842 ROTATE = 45 DEG )

;
SEXT SD1 =(L = 0.5 K2 = -12.4806458299 )
SD2 =(L = 0.5 K2 = -4.0425277287 )
SF1 =(L = 0.3 K2 = 7.5 )
SF2 =(L = 0.3 K2 = 4.676677817 )
SD3 =(L = 0.5 K2 = -7.6755095107 )
SF3 =(L = 0.3 K2 = 4.6129089171 )
SD4 =(L = 0.5 K2 = -9.9729618226 )
SF4 =(L = 0.3 K2 = 7.4734409919 )
SD8 =(L = 0.5 K2 = -10.6478971137 )
SF7 =(L = 0.3 K2 = 4.3630241617 )
SD7 =(L = 0.5 K2 = -7.7611544612 )
SF8 =(L = 0.3 K2 = 7.478821482 )
SD5 =(L = 0.5 K2 = -11.7813473075 )
SF6 =(L = 0.3 K2 = 5.5036721741 )
SF5 =(L = 0.3 K2 = 7.5 )
SD6 =(L = 0.5 K2 = -4.1768773594 )

;
SOL ESOL20 =(BZ = 1 DPX = 0.05 BOUND = 1 CHI1 = -0.05
GEO = 1 )
ESOL10 =(BZ = 1 DX = -0.0550302524 DY = 1.13579424E-3
DZ = 1.37643375E-3 BOUND = 1 CHI1 = 0.0499787186
CHI2 = -1.0311036E-3 CHI3 = -1.93343896E-6 )
ESOL1 =(BZ = 1 DX = 0.0550302524 DY = 1.13579424E-3
DZ = 1.37643375E-3 BOUND = 1 CHI1 = -0.0499787471
CHI2 = -1.02971949E-3 CHI3 = 5.34428292E-5 )
ESOL2 =(BZ = 1 DPX = 0.05 BOUND = 1 CHI1 = 0.05
GEO = 1 )

;
MARK IP =(ALPHAX = -1.36999489E-6 BETAX = 1.0000041849
ALPHAY = -6.08065897E-6 BETAY = 9.99995439E-3
EX = -5.01695036E-9 EPX = -7.0229286E-11 EY = 7.5014079E-12
EPY = 5.90429148E-9 R1 = -1.93346041E-6 R2 = 1.24411385E-8
R3 = -8.92499583E-7 R4 = -1.93559792E-6 DX = 3.0442027E-16
DPX = -1.4611365E-16 DY = 6.3340916E-18 DPY = -1.1702963E-15
EMIX = 1.85E-8 EMY = 1.85E-10 DP = 8E-3 )
CELLF =(ALPHAX = -7.330751E-3 BETAX = 17.2888471779
PSIX = 36.1817213212 ALPHAY = 7.00366572E-3
BETAY = 3.047809648 PSYI = 33.7005046918 EX = 0.52419717
EPX = 1.85663627E-3 EY = 1.14637608E-8 EPY = 6.74201723E-9
R1 = 2.15327591E-8 R2 = -5.0381567E-7 R3 = 1.26420063E-8
R4 = 1.26441109E-7 DX = 6.6615565E-16 DPX = 7.1833237E-17
DY = -2.2469639E-16 DPY = 1.7773679E-17 EMIX = 1.85E-8
EMY = 1.85E-10 DP = 8E-3 GEO = 1 )
WSYM =(ALPHAX = 1.3546851E-6 BETAX = 39.3963590603
PSIX = 42.5034949615 ALPHAY = 5.99203239E-6
BETAY = 26.9085755686 PSYI = 39.24854511
EX = 0.8000000073 EPX = -8.4005983E-10 EY = -1.51625859E-8
EPY = 2.56689099E-9 R1 = -2.29049933E-8 R2 = -2.79211787E-6
R3 = 3.14222972E-9 R4 = -1.39005076E-8 DX = 1.0768809E-15
DPX = 4.6378973E-17 DY = -6.0003544E-16 DPY = -1.2333005E-17
EMIX = 1.85E-8 EMY = 1.85E-10 DP = 8E-3 )
TSYM =(ALPHAX = -2.50684442E-6 BETAX = 1.6097098906
PSIX = 81.1917422321 ALPHAY = 1.56055438E-6
BETAY = 7.7953612473 PSYI = 76.5991559075
EX = -4.46117873E-9 EPX = 0.1034431794 EY = 4.57207165E-9
EPY = -4.27289657E-9 R1 = -2.14722585E-7 R2 = 3.12776671E-8
R3 = 3.99171825E-9 R4 = -4.29238426E-8 DX = 4.2819507E-16
DPX = 1.3070048E-17 DY = -2.4254831E-16 DPY = -3.5684342E-17
EMIX = 1.85E-8 EMY = 1.85E-10 DP = 8E-3 )
CELLR =(ALPHAX = 2.52085059E-6 BETAX = 22.1561921409
PSIX = 86.0477621033 ALPHAY = -7.19822289E-6
BETAY = 5.80490366 PSYI = 78.6787801997
EX = 1.72438806E-8 EPX = -8.4205645E-10 EY = 4.2084475E-10
EPY = -2.6796019E-10 R1 = 4.83560894E-8 R2 = 5.31225412E-7
R3 = -2.35418813E-9 R4 = 1.62156666E-7 DX = 1.5014184E-16
DPX = 7.1466097E-17 DY = -1.0767245E-16 DPY = 5.1633422E-17
EMIX = 1.85E-8 EMY = 1.85E-10 DP = 8E-3 )

;
LINE WIG =(LW0 BW1 LW BW2 LW BW3 LW BW2 LW BW4 LW0)
WIGL =(LW0 BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW4 LW0)

;
LINE LSD =(LXSD SD SD LXSD) LSF=(LXSF SF SF LXSF)
LSD1 =(LXSD SD1 LXSD) LSD2=(LXSD SD2 LXSD)
LSD3 =(LXSD SD3 LXSD) LSD4=(LXSD SD4 LXSD)
LSD5 =(LXSD SD5 LXSD) LSD6=(LXSD SD6 LXSD)
LSD7 =(LXSD SD7 LXSD) LSD8=(LXSD SD8 LXSD)
LSF1 =(LXSF SF1 LXSF) LSF2=(LXSF SF2 LXSF)
LSF3 =(LXSF SF3 LXSF) LSF4=(LXSF SF4 LXSF)
LSF5 =(LXSF SF5 LXSF) LSF6=(LXSF SF6 LXSF)
LSF7 =(LXSF SF7 LXSF) LSF8=(LXSF SF8 LXSF)
TRANS3=( CELLR QRF ACC QX0 QX0 ACC QX1 QX1 LX0 BT1 LX1 QX2 QX2
LX2 QX3 QX3 LX3)

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TRANS4=( BT1 LX1 QX2 QX2
          LX2 QX3 QX3 LX3)
TRANS4H=( BT2 LX1 QX2 QX2
           LX2 QX3 QX3 LX3)
;
LINE SUPPO=(
QF L2 B LSD1 QD QD
L1 B LXS2 QS2 LS2 QS1
QS2
QS1 LS1 B )
SUPPI=(
QF L2 B LSD5 QD QD
L1 B LXS2 QS2 LS2 QS1
QS2
QS1 LS1 B )
SUPPI1=(
QF L2 B LSD4 QD QD
L1 B LXS2 QS2 LS2 QS1
QS2
QS1 LS1 B )
SUPPI11=(
QF L2 B LSD8 QD QD
L1 B LXS2 QS2 LS2 QS1
QS2
QS1 LS1 B );
CELL =(QF LXS2 B L1 QD QD LXS1 B L2 QF)
CELLA =(QF L2 B LXS1 QD QD L1 B LXS2 QF)
CELLSD1=(QF LXS2 B L1 QD QD LSD1 B L2 QF)
CELLSD2=(QF LXS2 B L1 QD QD LSD2 B L2 QF)
CELLSD3=(QF L2 B LSD3 QD QD L1 B LXS2 QF)
CELLSD4=(QF L2 B LSD4 QD QD L1 B LXS2 QF)
CELLSD5=(QF LXS2 B L1 QD QD LSD5 B L2 QF)
CELLSD6=(QF LXS2 B L1 QD QD LSD6 B L2 QF)
CELLSD7=(QF L2 B LSD7 QD QD L1 B LXS2 QF)
CELLSD8=(QF L2 B LSD8 QD QD L1 B LXS2 QF)
CELLSF1=(QF LSF1 B L1 QD QD LXS1 B L2 QF)
CELLSF2=(QF LSF2 B L1 QD QD LXS1 B L2 QF)
CELLSF3=(QF L2 B LXS1 QD QD L1 B LSF3 QF)
CELLSF4=(QF L2 B LXS1 QD QD L1 B LSF4 QF)
CELLSF5=(QF LSF5 B L1 QD QD LXS1 B L2 QF)
CELLSF6=(QF LSF6 B L1 QD QD LXS1 B L2 QF)
CELLSF7=(QF L2 B LXS1 QD QD L1 B LSF7 QF)
CELLSF8=(QF L2 B LXS1 QD QD L1 B LSF8 QF)
CELLS21=(QF LSF2 B L1 QD QD LSD1 B L2 QF)
CELLS33=(QF L2 B LSD3 QD QD L1 B LSF3 QF)
CELLS44=(QF L2 B LSD4 QD QD L1 B LSF4 QF)
CELLS65=(QF LSF6 B L1 QD QD LSD5 B L2 QF)
CELLS77=(QF L2 B LSD7 QD QD L1 B LSF7 QF)
CELLS88=(QF L2 B LSD8 QD QD L1 B LSF8 QF)
CELLM=(CELLF CELL) COIM=(CELLF COL) RFM=(CELLF RF)
RFMS=(CELLF RFS) RFML=(CELLF RFL)
WIGINSH=(QF LXS2 B L1 QD QD LXS1 B LXW4 QW0S QW0S
          LXW1 B LXW2 QW1S QW1S LXW3 B LXW4 QW2S QW2S
          LXW1 B LXW2 QW3S QW3S LXW3 B LXW4 QW4S QW4S
          LXW1 B LXW2 QW5S QW5S LXW0S WIG
          QW6S QW6S WIGL QW7S QW7S WIGL QW8S)
WIGINS =(CELLF WIGINSH WSYM
          QW8S WIGL QW7S QW7S WIGL QW6S QW6S WIG LXW0S
          QW5S QW5S LXW2 B LXW1
          QW4S QW4S LXW4 B LXW3 QW3S QW3S LXW2 B LXW1
          QW2S QW2S LXW4 B LXW3 QW1S QW1S LXW2 B LXW1
          QW0S QW0S LXW4 B LSD3 QD QD L1 B LXS2 QF)
WIGINSHA=(QF LXS2 B L1 QD QD LSD7 B LXW4 QW0L QW0L
          LXW1 B LXW2 QW1L QW1L LXW3 B LXW4 QW2L QW2L
          LXW1 B LXW2 QW3L QW3L LXW3 B LXW4 QW4L QW4L
          LXW1 B LXW2 QW5L QW5L LXW0L WIG
          QW6L QW6L WIGL QW7L QW7L WIGL QW8L)
WIGINSA=(WIGINSHA
          QW8L WIGL QW7L QW7L WIGL QW6L
          QW6L WIG LXW0L QW5L QW5L LXW2 B LXW1
          QW4L QW4L LXW4 B LXW3 QW3L QW3L LXW2 B LXW1
          QW2L QW2L LXW4 B LXW3 QW1L QW1L LXW2 B LXW1
          QW0L QW0L LXW4 B LXS1 QD QD L1 B LXS2 QF)
WIGINSHS=(QF LSF B L1 QD QD LSD B LXW4 QW0S QW0S
          LXW1 B LXW2 QW1S QW1S LXW3 B LXW4 QW2S QW2S
          LXW1 B LXW2 QW3S QW3S LXW3 B LXW4 QW4S QW4S
          LXW1 B LXW2 QW5S QW5S LXW0S WIG
          QW6S QW6S WIGL QW7S QW7S WIGL QW8S)
WIGINSHL=(QF LSF B L1 QD QD LSD B LXW4 QW0L QW0L
          LXW1 B LXW2 QW1L QW1L LXW3 B LXW4 QW2L QW2L
          LXW1 B LXW2 QW3L QW3L LXW3 B LXW4 QW4L QW4L
          LXW1 B LXW2 QW5L QW5L LXW0L WIG
          QW6L QW6L WIGL QW7L QW7L WIGL QW8L)
WIGMS=(CELLF WIGINSHS WSYM)
WIGML=(CELLF WIGINSHL WSYM)
ASCH=(IP -COLO CELL CELLSD1 CELLSD2 CELL CELLSD2 CELLSD1
      CELL CELLSD1 CELLSF1 CELL CELLSF1 CELLSF2
      CELL CELLS21 CELL CELLSD1 WIGINS
      CELLA CELLS33
      CELLA CELLSF3 CELLSD4 CELLA CELLS44 CELLA CELLSF4
      CELLSD3 CELLA CELLS33 CELLA CELLSF3 CELLSD4 CELLA
      RFS)
ASCHA=(IP -COLI CELL CELLSD5 CELLSD6 CELL CELLSD6 CELLSD5
      CELL CELLSD5 CELLSF5 CELL CELLSF5 CELLSF6
      CELL CELLS65 CELL CELLSD5 -WIGINSA
      CELLA CELLS77
      CELLA CELLSF7 CELLSD8 CELLA CELLS88 CELLA CELLSF8
      CELLSD7 CELLA CELLS77 CELLA CELLSF7 CELLSD8 CELLA
      RFL)
IRSEC=(CELLF COLI IP -COLO)

```

```

      ASC=(ASCH -ASCHA);
LINE COLO=(
  SUPPO  LX0   QA10   QA10   LA10   QA20   QA20
          LA20   QA30   QA30   LA30   QA40   QA40
          LA40   QA50   QA50   LA50   QA60   QA60
  LXC    LXC    LC9    QC8    QC8    LX0    QK80   LX0    BH40
  LC8    QK70   LX0    QC7    QC7    LC7
  QK60   LX0    QC6    QC6    LC6
  QK50                   LC5    BH20
                   LC5    QK30
  LC3    VB2    LI3    VB3    LX0    QK20   LX0
  QC2    QC2    LI2
  QC1    QC1    LI1    ESOL10  LXS    ESOL20 );
LINE COLI=(
  SUPPI  LX0   QA1I   QA1I   LA1I   QA2I   QA2I
          LA2I   QA3I   QA3I   LA3I   QA4I   QA4I
          LA4I   QA5I   QA5I   LA5I   QA6I   QA6I
  LXC    LXC    LC9    QC8    QC8    LX0    QK8    LX0    BH4
  LC8    QK7    LX0    QC7    QC7    LC7
  QK6    LX0    QC6    QC6    LC6
  QK5                   LC5    BH2
                   LC5    QK3
  LC3    VB2    LI3    VB3    LX0    QK2    LX0
  QC2    QC2    LI2
  QC1    QC1    LI1    ESOL1   LXS    ESOL2 );
LINE COLMI=(CELLF COLI);
LINE COLMO=(CELLF COLO);
LINE ACC =(LRF  CAV  LRF)
  RFC =(LRF  ACC  QRD  QRD  ACC  QRF)
  RFCM=(CELLR RFC);
LINE RFS=(
  SUPP1S LX0   QR3S   QR3S   LR3S
  QR2S   QR2S   LR2S   QR1S   QR1S   LR1S   QR0S   QR0S
  LX0    TRANS4  TSYM  -TRANS4H LX0  QX1   QX1   ACC
  QX0    QX0    ACC    QRF    CELLR);
LINE RFL=(
  SUPP1L LX0
  QM5L   QM5L   LM5L   QM4L   QM4L   LM4L   QM3L   QM3L   LM3L
  QM2L   QM2L   LM2L   QM1L   QM1L   ACC   QM0L   QM0L   ACC
  QRF    CELLR  4*RFC);
CAVI CAV=(VOLT= 2.9460  MV FREQ=500 MHZ)
;
  FFS USE=ASC;
  FREE QM* LM*
  FIT CELLR BX @ 1 BY @ 1 AX 0 1 AY 0 1
  FIT BX 1 1 BY .01 1 AX 0 1 AY 0 1 GX 0 1
  FIT NX 27.12 1 NY 25.15 1
  END
STOP

```

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1- 28/08/90 103050909 MEMBER NAME \SADIN4 *.FORT SAD -- 00000000
13.5 GEV COLLIDER FOR THE KEK B FACTORY CRAB CROSSING (\CLR09)
MOMENTUM= 3.5 GEV;
OFF ECHO;OFF EMIT COD CTIME RAD RFSW;

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LER (crab-crossing)

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;
DRIFT LXS =(L = 1.1 ) LI1 =(L = 0.7 )
LI2 =(L = 3.7924819781 ) LX0 =(L = 0.2 )
LI3 =(L = 6.4363470181 ) LC3 =(L = 1.9013127193 )
LC4 =(L = 4.1696369565 ) LC5 =(L = 4.0165006576 )
LC6 =(L = 6.5800755698 ) LC7 =(L = 3.0825865192 )
LC8 =(L = 4.1902967428 ) LC9 =(L = 0.5884912028 )
LXC =(L = 3 ) LA50 =(L = 2 )
LA40 =(L = 3.3639132978 ) LA30 =(L = 3.3654692826 )
LA20 =(L = 2.6398499321 ) LA10 =(L = 2 )
LB =(L = 1.7 ) LS1 =(L = 2.4646142009 )
LS2 =(L = 5.6949239224 ) L2 =(L = 1.745 )
LI =(L = 0.95 ) LXSD =(L = 0.53 ) LXSF =(L = 1.395 )
LIW =(L = 1.725 ) LIW =(L = 0.93 )
LIWS =(L = 1.72 ) LWO =(L = 0.2 ) LW =(L = 0.3 )
IM5S =(L = 3.4152088974 ) IM4S =(L = 4.063328264 )
IM3S =(L = 3.8637546613 ) IM2S =(L = 3.9593036119 )
LRF =(L = 3.05 ) LX1 =(L = 2.6767340731 )
LX2 =(L = 2.4169002935 ) LX3 =(L = 0.2 )
LBV1 =(L = 1.445 ) LBV2 =(L = 2 )
LR1L =(L = 1.8592330142 ) LR2L =(L = 8.453552459 )
LR3L =(L = 4.5704076703 ) L1WL =(L = 1.82 )
LA1I =(L = 1.7051905509 ) LA2I =(L = 3.3091288141 )
LA3I =(L = 3.86209259 ) LA4I =(L = 3.9439321039 )
LA5I =(L = 3.9488884535 )
;
BEND BH20 =(L = 5 ANGLE = -0.0137201932 E1 --6.86009662E-3
E2 --6.86009662E-3 )
BH40 =(L = 2.5 ANGLE = -0.0118451977 E1 --5.92259883E-3
E2 --5.92259883E-3 )
BCELL =(L = 0.27 ANGLE = 0.0186999563 E1 = 9.349978E-3
E2 = 9.349978E-3 )
BW1 =(L = 0.25 ANGLE = 0 )
BW2 =(L = 0.5 ANGLE = 0 )
BW3 =(L = 0.5 ANGLE = 0 )
BW4 =(L = 0.25 ANGLE = 0 )
BT2 =(L = 1 ANGLE = -0.0525 E1 = -0.02625
E2 = -0.02625 )
BV1 =(L = 3.18 ANGLE = 0.02162 E2 = 0.02162
ROTATE = 90 DEG )
BV2 =(L = 3.18 ANGLE = -0.02162 E1 = -0.02162
ROTATE = 90 DEG )
BT1 =(L = 1 ANGLE = 0.0525 E1 = 0.02625 E2 = 0.02625 )
BH4 =(L = 2.5 ANGLE = 0.0118451977 E1 = 5.92259883E-3
E2 = 5.92259883E-3 )
BH2 =(L = 5 ANGLE = 0.0137201932 E1 = 6.86009662E-3
E2 = 6.86009662E-3 )
;
QUAD QC1 =(L = 0.1 K1 = -0.3289755599 )
QC2 =(L = 0.2 K1 = 0.1240942735 )
QK20 =(L = 0.2 K1 = -0.0161122269 ROTATE = 45 DEG )
QK30 =(L = 0.2 K1 = 3.46316724E-3 ROTATE = 45 DEG )
QC3 =(L = 0.2 K1 = -0.0348484621 )
QK50 =(L = 0.2 K1 = -0.0182515409 ROTATE = 45 DEG )
QC6 =(L = 0.2 K1 = 0.116458841 )
QK60 =(L = 0.2 K1 = 0.0455799089 ROTATE = 45 DEG )
QC7 =(L = 0.2 K1 = -0.1203990515 )
QK70 =(L = 0.2 K1 = -0.059321164 ROTATE = 45 DEG )
QK80 =(L = 0.2 K1 = 0.0787130931 ROTATE = 45 DEG )
QC8 =(L = 0.2 K1 = 0.0692709329 )
QA60 =(L = 0.2 K1 = 0.062299912 )
QA50 =(L = 0.2 K1 = -0.0925709044 )
QA40 =(L = 0.2 K1 = 0.0188393652 )
QA30 =(L = 0.2 K1 = 0.0227009934 )
QA20 =(L = 0.2 K1 = -0.0669922778 )
QA10 =(L = 0.2 K1 = 0.0718653044 )
QS1 =(L = 0.2 K1 = -0.0790087037 )
QS2 =(L = 0.2 K1 = 0.1294065624 )
QD =(L = 0.1 K1 = -0.1380902676 )
QF =(L = 0.1 K1 = 0.1392771557 )
QW0S =(L = 0.12 K1 = 0.1313836333 )
QW1S =(L = 0.12 K1 = -0.098733284 )
QW2S =(L = 0.12 K1 = 0.1423014363 )
QW3S =(L = 0.12 K1 = -0.1056825656 )
QW4S =(L = 0.12 K1 = 0.0650961732 )
QW5S =(L = 0.12 K1 = -0.0447715288 )
QW6S =(L = 0.12 K1 = 0.0704228612 )
QW7S =(L = 0.12 K1 = -0.0509949903 )
QW8S =(L = 0.12 K1 = 0.0166175836 )
QM5S =(L = 0.2 K1 = 0.1451376815 )
QM4S =(L = 0.2 K1 = -0.1370799783 )
QM3S =(L = 0.2 K1 = 0.1844763279 )
QM2S =(L = 0.2 K1 = -0.0973522372 )
QM1S =(L = 0.2 K1 = 0.1505509943 )
QM0S =(L = 0.15 K1 = -0.0993611794 )
QRF =(L = 0.15 K1 = 0.1094850999 )
QRD =(L = 0.15 K1 = -0.0973343545 )
QX0 =(L = 0.15 K1 = -0.0698322029 )
QX1 =(L = 0.15 K1 = 0.1900178001 )
QX2 =(L = 0.15 K1 = -0.1687052607 )
QX3 =(L = 0.15 K1 = 0.1691202561 )
QR0L =(L = 0.15 K1 = 7.00447145E-3 )
QR1L =(L = 0.2 K1 = 0.1312734163 )
QR2L =(L = 0.2 K1 = -0.1186320058 )
QR3L =(L = 0.2 K1 = 0.1369134017 )
QW0L =(L = 0.12 K1 = 0.1286682211 )

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QW1L  =(L = 0.12      K1 = -0.1003036539 )
QW2L  =(L = 0.12      K1 = 0.143374166 )
QW3L  =(L = 0.12      K1 = -0.1097429542 )
QW4L  =(L = 0.12      K1 = 0.0823042698 )
QW5L  =(L = 0.12      K1 = -0.042347718 )
QW6L  =(L = 0.12      K1 = 0.0601027884 )
QW7L  =(L = 0.12      K1 = -0.0505283748 )
QW8L  =(L = 0.12      K1 = 0.0257991707 )
QA1I  =(L = 0.2 K1 = 0.1025852448 )
QA2I  =(L = 0.2 K1 = -0.075039622 )
QA3I  =(L = 0.2 K1 = 0.0105308175 )
QA4I  =(L = 0.2 K1 = 0.0161804229 )
QA5I  =(L = 0.2 K1 = -0.0683096288 )
QA6I  =(L = 0.2 K1 = 0.0416348462 )
QK8   =(L = 0.2 K1 = -0.0787130931 ROTATE = 45 DEG )
QK7   =(L = 0.2 K1 = 0.059321164  ROTATE = 45 DEG )
QK6   =(L = 0.2 K1 = -0.0455799089 ROTATE = 45 DEG )
QK5   =(L = 0.2 K1 = 0.0182515409  ROTATE = 45 DEG )
QK3   =(L = 0.2 K1 = -3.46316724E-3 ROTATE = 45 DEG )
QK2   =(L = 0.2 K1 = 0.0161122269  ROTATE = 45 DEG )

;
SEXT SD1  =(L = 0.22      K2 = -11.8761932591 )
      SD2  =(L = 0.22      K2 = -4.569659797 )
      SD1A =(L = 0.22      K2 = -9.8564615836 )
      SF1  =(L = 0.15      K2 = 3.8494559515 )
      SF2  =(L = 0.15      K2 = 2.095632206 )
      SD1B =(L = 0.22      K2 = -2.4161920371 )
      SD3  =(L = 0.22      K2 = -4.0084052636 )
      SF3  =(L = 0.15      K2 = 3.7601768216 )
      SD4A =(L = 0.22      K2 = -12.5580604771 )
      SF4  =(L = 0.15      K2 = 6.6960645584 )
      SD3A =(L = 0.22      K2 = -7.4220624669 )
      SF3A =(L = 0.15      K2 = 2.8201790022 )
      SD4  =(L = 0.22      K2 = -12.1095120469 )
      SD8  =(L = 0.22      K2 = -11.044944986 )
      SF7A =(L = 0.15      K2 = 3.4306432147 )
      SD7A =(L = 0.22      K2 = -7.3120813494 )
      SF8  =(L = 0.15      K2 = 7.1369224031 )
      SD8A =(L = 0.22      K2 = -12.0500264952 )
      SF7  =(L = 0.15      K2 = 4.3212174665 )
      SD7  =(L = 0.22      K2 = -6.3208470136 )
      SD5B =(L = 0.22      K2 = -3.3703519214 )
      SF6  =(L = 0.15      K2 = 6.1530676321 )
      SF5  =(L = 0.15      K2 = 4.824626207 )
      SD5A =(L = 0.22      K2 = -11.4681067233 )
      SD6  =(L = 0.22      K2 = -4.0827921809 )
      SD5  =(L = 0.22      K2 = -11.4431646208 )

;
SOL  ESOL20 =(BZ = 1 BOUND = 1 GEO = 1 )
      ESOL10 =(BZ = 1 BOUND = 1 )
      ESOL1  =(BZ = 1 BOUND = 1 CHI1 = 1.1362439E-16
              CHI2 = 1.293618E-18 CHI3 = -2.6577937E-19 )
      ESOL2  =(BZ = 1 BOUND = 1 GEO = 1 )

;
MARK IP  =(ALPHAX = -2.51712524E-5 BETAX = 1.0000079631
          ALPHAY = -2.89306229E-5 BETAY = 9.99976306E-3
          EX = 2.54805206E-5 EPX = 3.95933459E-5 EY = 5.87550833E-7
          EY = 1.53403151E-4 R1 = -1.2625297E-14 R2 = 2.3277748E-10
          R3 = 8.42433296E-8 R4 = -5.1806464E-12 DX = 1.3137576E-17
          DPX = -2.1731706E-18 DY = 2.8468868E-19 DPY = 4.3744752E-17
          EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
      CELLF =(ALPHAX = -3.09985557E-6 BETAX = 17.3747908544
              PSIX = 33.6778622032 ALPHAY = 2.57690835E-5
              BETAY = 3.0289766681 PSIY = 33.7352217071
              EX = 0.4968235006 EPX = -1.07645646E-5 EY = 1.26008055E-5
              EY = -8.47201524E-6 R1 = -3.37486851E-9 R2 = -1.48638077E-8
              R3 = 1.3900967E-10 R4 = 1.40079499E-8 DX = -4.1886469E-17
              DPX = -2.0961337E-18 DY = 2.2062765E-18 DPY = -2.9090604E-18
              EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 GEO = 1 )
      WSYM  =(ALPHAX = -5.021521E-7 BETAX = 11.714881863
              PSIX = 39.9610475129 ALPHAY = 3.02961031E-5
              BETAY = 38.8325404551 PSIY = 39.2330047364
              EX = 0.500048828 EPX = -1.31099095E-5 EY = 9.68720703E-5
              EY = -8.51608816E-7 R1 = -1.17039674E-8 R2 = -1.19109904E-7
              R3 = -2.3453643E-10 R4 = 1.47583837E-9 DX = -3.4394019E-17
              DPX = -2.5527514E-18 DY = 2.7895027E-17 DPY = -4.3066573E-19
              EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
      CELLR =(ALPHAX = -1.22930459E-5 BETAX = 20.5113343623
              PSIX = 79.8068887895 ALPHAY = -5.66364834E-6
              BETAY = 5.2413433179 PSIY = 74.9259680599
              EX = -2.05627645E-4 EPX = 2.75419801E-6 EY = -3.99631854E-6
              EY = 7.13449886E-6 R1 = -2.02948026E-9 R2 = -6.25617256E-8
              R3 = -3.058949E-10 R4 = 1.28463744E-8 DX = -8.4015857E-18
              DPX = 2.9115467E-18 DY = 1.2487255E-18 DPY = 2.2672342E-18
              EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )
      TSYM  =(ALPHAX = 1.16697054E-5 BETAX = 12.5046879083
              PSIX = 90.9906314583 ALPHAY = 6.11831673E-6
              BETAY = 13.1292677476 PSIY = 81.7868561442
              EX = -7.33655061E-5 EPX = 0.0472905398 EY = -0.0999910463
              EY = 4.03939667E-6 R1 = 5.4151007E-10 R2 = -6.77498753E-8
              R3 = -6.7647697E-10 R4 = 1.14947874E-9 DX = -4.7033223E-17
              DPX = 1.8223902E-19 DY = 1.1926585E-17 DPY = 1.1178295E-18
              EMIX = 1.85E-8 EMIY = 1.85E-10 DP = 5E-3 )

;
LINE B =(BCELL LB BCELL)

;
LINE WIG3 =( LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW
              BW2 LW BW4 LWO )
WIG4 =( LWO BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW3 LW )

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      BW2 LW BW4 LW0)
WIG5  =( LW0 BW1 LW BW2 LW BW3 LW BW2 LW BW3 LW BW2 LW BW3 LW
      BW2 LW BW3 LW BW2 LW BW4 LW0)
;
LINE  LSD  =(LX0 SD SD LXSD) LSD1A =(LXSD SD1 LX0)
      LSD1 =(LX0 SD1 LXSD) LSD2=(LX0 SD2 LXSD)
      LSD1A=(LX0 SD1A LXSD) LSD1B=(LX0 SD1B LXSD)
      LSD3 =(LX0 SD3 LXSD) LSD4=(LX0 SD4 LXSD)
      LSD3A =(LX0 SD3A LXSD) LSD4A=(LX0 SD4A LXSD)
      LSD5 =(LX0 SD5 LXSD) LSD6=(LX0 SD6 LXSD)
      LSD5A=(LX0 SD5A LXSD) LSD5B=(LX0 SD5B LXSD)
      LSD7 =(LX0 SD7 LXSD) LSD8=(LX0 SD8 LXSD)
      LSD7A =(LX0 SD7A LXSD) LSD8A=(LX0 SD8A LXSD)
      LSF1 =(LX0 SF1 LXSf) LSF2=(LX0 SF2 LXSf)
      LSF3 =(LX0 SF3 LXSf) LSF4=(LX0 SF4 LXSf)
      LSF3A =(LX0 SF3A LXSf)
      LSF5 =(LX0 SF5 LXSf) LSF6=(LX0 SF6 LXSf)
      LSF7 =(LX0 SF7 LXSf) LSF8=(LX0 SF8 LXSf)
      LSF7A =(LX0 SF7A LXSf)
      TRANS4=( BT1 LX1 QX2 QX2
               LX2 QX3 QX3 LX3
               BV1 LBV1 BV2 LBV2)
      TRANS4H=( BT2 LX1 QX2 QX2
                LX2 QX3 QX3 LX3
                BV1 LBV1 BV2 LBV2)
;
LINE  SUPPI=(
      QF    L2    B    -LSD5    QD    QD
      L1    B    L2    QS2
      QS2
      QS1    LS1    B    )
      SUPPO=(
      QF    L2    B    -LSD1    QD    QD
      L1    B    L2    QS2
      QS2
      QS1    LS1    B    )
      SUPPIS=(
      QF    L2    B    L1    QD    QD
      LSD4   B    L2    QS2
      QS2
      QS1    LS1    B    )
      SUPPIL=(
      QF    L2    B    L1    QD    QD
      LSD8   B    L2    QS2
      QS2
      QS1    LS1    B    )
      SUPPX=(
      QF    L2    B    LSD    QD    QD
      L1    B    L2    QS2
      QS2
      QS1    LS1    B    );
LINE  CELL  =(QF L2 B L1 QD QD L1 B L2 QF)
      CSD1=(QF L2 B L1 QD QD LSD1 B L2 QF)
      CSD1A=(QF L2 B L1 QD QD LSD1A B L2 QF)
      CSD1B=(QF L2 B L1 QD QD LSD1B B L2 QF)
      CSD2=(QF L2 B L1 QD QD LSD2 B L2 QF)
      CSD3=(QF L2 B L1 QD QD LSD3 B L2 QF)
      CSD3A=(QF L2 B L1 QD QD LSD3A B L2 QF)
      CSD4=(QF L2 B L1 QD QD LSD4 B L2 QF)
      CSD4A=(QF L2 B L1 QD QD LSD4A B L2 QF)
      CSF1=(QF LSF1 B L1 QD QD L1 B L2 QF)
      CSF2=(QF LSF2 B L1 QD QD L1 B L2 QF)
      CSF3=(QF LSF3 B L1 QD QD L1 B L2 QF)
      CSF3A=(QF LSF3A B L1 QD QD L1 B L2 QF)
      CSF4=(QF LSF4 B L1 QD QD L1 B L2 QF)
      CS21B=(QF LSF2 B L1 QD QD LSD1B B L2 QF)
      CS34=(QF LSF3 B L1 QD QD LSD4 B L2 QF)
      CS34A=(QF LSF3 B L1 QD QD LSD4A B L2 QF)
      CS34AA=(QF LSF3A B L1 QD QD LSD4 B L2 QF)
      CS43=(QF LSF4 B L1 QD QD LSD3 B L2 QF)
      CS43A=(QF LSF4 B L1 QD QD LSD3A B L2 QF)
      CSD5=(QF L2 B L1 QD QD LSD5 B L2 QF)
      CSD5A=(QF L2 B L1 QD QD LSD5A B L2 QF)
      CSD5B=(QF L2 B L1 QD QD LSD5B B L2 QF)
      CSD6=(QF L2 B L1 QD QD LSD6 B L2 QF)
      CSD7=(QF L2 B L1 QD QD LSD7 B L2 QF)
      CSD7A=(QF L2 B L1 QD QD LSD7A B L2 QF)
      CSD8=(QF L2 B L1 QD QD LSD8 B L2 QF)
      CSD8A=(QF L2 B L1 QD QD LSD8A B L2 QF)
      CSF5=(QF LSF5 B L1 QD QD L1 B L2 QF)
      CSF6=(QF LSF6 B L1 QD QD L1 B L2 QF)
      CSF7=(QF LSF7 B L1 QD QD L1 B L2 QF)
      CSF7A=(QF LSF7A B L1 QD QD L1 B L2 QF)
      CSF8=(QF LSF8 B L1 QD QD L1 B L2 QF)
      CS65B=(QF LSF6 B L1 QD QD LSD5B B L2 QF)
      CS78=(QF LSF7 B L1 QD QD LSD8 B L2 QF)
      CS78A=(QF LSF7 B L1 QD QD LSD8A B L2 QF)
      CS78AA=(QF LSF7A B L1 QD QD LSD8 B L2 QF)
      CS87=(QF LSF8 B L1 QD QD LSD7 B L2 QF)
      CS87A=(QF LSF8 B L1 QD QD LSD7A B L2 QF)
      CELLM=(CELLF CELL) COIM=(CELLF COL) RFMS=(CELLF RFS)
      RFML=(CELLF RFL)
      WIGINSH=(QF L2 B L1 QD QD L1 B L2W QW0S QW0S
               L2W B L1W QW1S QW1S L1W B L2W QW2S QW2S
               L2W B L1W QW3S QW3S L1W B L2W QW4S QW4S
               L2W B L1WS QW5S QW5S WIG3
               QW6S QW6S WIG5 QW7S QW7S WIG5 QW8S)
      WIGINS =(CELLF WIGINSH WSYM
               QW8S WIG5 QW7S QW7S WIG5 QW6S
               QW6S WIG3 QW5S QW5S

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L1WS B L2W QW4S QW4S L2W B L1W QW3S QW3S
L1W B L2W
QW2S QW2S L2W B L1W QW1S QW1S L1W B L2W
QW0S QW0S L2W B L1 QD QD LSD3 B L2 QF)
WIGINSHA=(QF L2 B -LSD7 QD QD L1 B L2W QW0L QW0L
L2W B L1W QW1L QW1L L1W B L2W QW2L QW2L
L2W B L1W QW3L QW3L L1W B L2W QW4L QW4L
L2W B L1WL QW5L QW5L WIG4
QW6L QW6L WIG5 QW7L QW7L WIG5 QW8L)
WIGINSA=(WIGINSHA
QW8L WIG5 QW7L QW7L WIG5 QW6L
QW6L WIG4 QW5L QW5L
L1WL B L2W QW4L QW4L L2W B L1W QW3L QW3L
L1W B L2W
QW2L QW2L L2W B L1W QW1L QW1L L1W B L2W
QW0L QW0L L2W B L1 QD QD L1 B L2 QF)
WIGMS=(CELLF WIGINSH WSYM)
WIGML=(CELLF WIGINSHA WSYM)
ASCH=(IP -COLO CELL CSD1 CSD2 CELL CSD2 CSD1A
CELL CSD1A CSF1 CELL CSF1 CSF2
CELL CS21B CELL CSD1B WIGINS
CELL CSD3
CSF3 CELL CS34A CELL CSD4A CSF4 CELL
CS43A CELL CSD3A CSF3A CELL CS34AA CELL
RFS)
ASCHA=(IP -COLI CELL CSD5 CSD6 CELL CSD6 CSD5A
CELL CSD5A CSF5 CELL CSF5 CSF6
CELL CS65B CELL CSD5B -WIGINSA
CELL CSD7
CSF7 CELL CS78A CELL CSD8A CSF8 CELL
CS87A CELL CSD7A CSF7A CELL CS78AA CELL
RFL)
ASC=(ASCH -ASCHA);
LINE COLO=(
SUPPO LX0 QA10 QA10 LA10 QA20 QA20
LA20 QA30 QA30 LA30 QA40 QA40
LA40 QA50 QA50 LA50 QA60 QA60
LXC LXC LC9 QC8 QC8 LX0 QK80 LX0 BH40
LC8 QK70 LX0 QC7 QC7 LC7
QK60 LX0 QC6 QC6 LC6
QK50 LC4 QC3 QC3 LC5 BH20
LC3 LI3 LC6 QK30 LX0
QC2 QC2 LI2
QC1 QC1 LI1 ESOL10 LXS ESOL20 );
LINE COLI=(
SUPPY LX0 QA1I QA1I LA1I QA2I QA2I
LA2I QA3I QA3I LA3I QA4I QA4I
LA4I QA5I QA5I LA5I QA6I QA6I
LXC LXC LC9 QC8 QC8 LX0 QK8 LX0 BH4
LC8 QK7 LX0 QC7 QC7 LC7
QK6 LX0 QC6 QC6 LC6
QK5 LC4 QC3 QC3 LC5 BH2
LC3 LI3 LC6 QK3 LX0
QC2 QC2 LI2
QC1 QC1 LI1 ESOL1 LXS ESOL2 );
LINE COIMI=(CELLF COLI) COLMX=(CELLF COLX) COLL=(IP -COLO);
LINE ACC =(LRF CAV LRF)
RFC =(QRF ACC QRD QRD ACC QRF)
RFCM=(CELLR RFC);
LINE RFL=(
SUPPIL LX0 QR3L QR3L LR3L
QR2L QR2L LR2L QR1L LR1L QR0L QR0L
LX0 TRANS4 TSYM -TRANS4H LX0 QX1 QX1 ACC
QX0 QX0 ACC QRF CELLR);
LINE RFS=(
SUPPIS LX0
QM5S QM5S LM5S QM4S QM4S LM4S QM3S QM3S LM3S
QM2S QM2S LM2S QM1S QM1S ACC QM0S QM0S ACC
QRF CELLR 4*RFC);
CAVI CAV=(VOLT= 1.3037 MV FREQ=500 MHZ)

FFS USE=ASC;
FREE QM* LM*
FIT CELLR BX @ 1 BY @ 1 AX 0 1 AY 0 1
FIT BX 1 1 BY .01 1 CX 0 1
FIT NX 27.21 1 NY 25.15 1 AX 0 1 AY 0 1
END
STOP

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