DESIGN OF THE BEAM TRANSPORT SYSTEM OF THE KEK B-FACTORY INJECTOR

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Abstract

The KEK 2.5-GeV linac will be upgraded for the KEKB project to supply 3.5-GeV positrons and 8-GeV electrons to the storage rings. The present electron and positron linacs are to be extended and joined by a 180° turn to form a "J"-shaped linear accelerator. This paper describes the beam transport system design of the KEKB injector linac. The layout of the quadrupole focusing magnets is determined while considering the transport system acceptance and the expected beam emittance. Design of the achromatic and isochronous 180° turn is also described.

Introduction

New asymmetric-energy collider rings (8.0 GeV e^- and 3.5 GeV e^+) will be constructed at TRISTAN for the KEK B-physics project. The most important aspect of the collider is its luminosity. To obtain a significant number of data events for physics studies, peak luminosity beyond 10^{33} $cm^{-2}s^{-1}$ and efficient operation are required. Direct injection of electrons and positrons from the linac to the storage rings and an increase in the beam intensity (especially for positrons) are of primary importance to reduce injection time. Present beam-quality parameters and those required for KEKB are summarized in Table 1.

Table 1
Machine parameters for the present and the KEKB injector

	(Present)	(KEKB)
Energy (e–)	2.5 GeV	8.0 GeV
Energy (e+)	2.5 GeV	3.5 GeV
Energy (e– for e+ production)	0.25 GeV	3.7 GeV
Charge (e–)	0.32 nC	1.28 nC
Charge (e+)	0.032 nC	0.64 nC
Charge (e– for e+ production)	10.0 nC	10.0 nC
Emittance (e–) [3σ]	0.54	≤ 2.3
Emittance (e+) [3σ]	5.9	≤ 13.9
σ_E/E (e–)	± 0.20 %	± 0.15 %
σ_E/E (e+)	± 0.22 %	± 0.25 %
bunch length σ_z	± 5 ps	± 5 ps

(Units of the emittances are 10^{-3}.π.rad.m.)

Upgrade of the present 2.5 GeV linac is necessary to achieve the higher beam energy and intensity. Acceleration energy of 8 GeV is attained by increasing the RF power (corresponding to an acceleration field: 8 to 20 MeV/m) and extending the accelerator (effective length: 320 to 456 m). To make full use of the existing facilities, the present electron and positron linacs will be extended upstream and joined by a 180° turn to form a "J"-shaped linear accelerator. Details concerning the re-formation are described in Ref. [1], while the layout is shown in Fig. 1. The positron generator unit will be moved downstream and the electron energy hitting the production target will be increased by a factor of 15. The positron yield is also expected to increase by the same ratio. As a consequence of the mentioned relocation, the beam transport system should also be renewed.

Beam Emittance of the KEKB Injector

To determine the transport system layout based on a consideration of the acceptance, we evaluated the emittances of the electron and positron beams. The pre-injector of the 2.5 GeV electron linac has already been upgraded in 1992 for studying high-intensity single-bunched beam acceleration. It comprises: (1) a 190-kV thermionic gun with a cathode area of 2 cm^2, (2) a 476-MHz sub-harmonic buncher (SHB) of a re-entrant type cavity, (3) double pre-bunchers of 5 and 3 cells of 0.75c traveling-wave cavities and (4) a buncher having a 1.2 m long accelerating structure of traveling-wave type. The beam-bunching section in Sector-A is covered with a 1.0 kG solenoidal magnetic field produced by Helmholz coils. Details concerning the pre-injector are described in Ref. [2]. The beam emittance at the exit of the buncher has been measured [3] with the beam spot size on the fluorescent screen by changing the focusing strength of the quadrupole magnet. The measured (1-σ extent) normalized emittance ($\gamma\beta\varepsilon$) is around 60 π.mm.mrad at 10 MeV for an 8 nC single-bunch beam ($\gamma=E_{beam}/m_e$, $\beta=v/c$). A simulation study of the beam bunching gives consistent results [4].

In the new scheme, the present pre-injector will be moved to the farthest upstream location of the J-linac. The SHB will be replaced by two new SHBs with resonant frequencies of 114 and 571 MHz for a higher beam charge. The electron beam emittance in the J-linac is supposed to be the same as the present value. In the following discussion, the normalized emittance is assumed to be 60 π.mm.mrad and the electron transport system is designed to accept 3-σ in phase space i.e., 540 π.mm.mrad. In the following discussion, we assume that there is no emittance growth and the absolute emittance (ε) decreases in proportion to the inverse of the beam energy, because we expect to control the wake-field effects.

Positrons are produced by hitting a 16 mm thick tantalum target with 3.7 GeV electrons. They are focused by a solenoidal magnetic field comprising a 45 mm long 20 kG field produced by a pulsed coil and a 8 m long 4 kG field by a DC magnet. The positron yield and its emittance are limited by the solenoid focusing system acceptance, whose value is 5900 π.mm.mrad. The positron transport system has been designed for this capability. No emittance growth was also assumed for positrons, since the current is low.

Transport system acceptance

The J-linac beam transport is basically a periodic system of quadrupole triplets. The acceptance of such a system is determined from various factors mainly, (a) the beam-line aperture, (b) the interval of the quads and (c) the betatron phase advance. For the case of a "regular unit", which comprises four 2-m accelerator structures and a quadrupole triplet, the acceptance is approximately $u = \pi a^2/L \sim 5$ π.mm.mrad for a phase advance of 90° per period, where the interval of the triplets (L) is 9.6 m and the aperture (a) is 7 mm. In the low energy region where the emittance is large, a greater acceptance is required, as illustrated in Fig. 2. It shows a comparison between the expected beam emittances and the designed transport acceptance. In Sector-A, which includes the pre-injector, the interval of the quads gradually varies as the emittance changes and the betatron wavelengths are 5.2 ~ 20 m. Sectors-B, C and the following Sector-1 have "regular units" where the quads are located every 9.6 m, and the betatron wavelength is about 40 m. As clearly shown in the Fig. 2, the acceptance in these sectors is much greater than the emittance. Nevertheless, it is necessary to control the beam blow-up due to transverse wake-field effects[5]. Between Sector-B and C, the electron beam changes direction in the 180° turn; its design is described in the next section.

The positron production target and the solenoidal focusing system are located in the first unit of Sector-2. Positrons produced by the electrons hitting the target are injected into the ring. In the following sectors, the transport system must be able to accept large-emittance positron beams. This is specially required in the two units which follow the solenoidal focusing system, since the positron energy is still low and its emittance large. In these units, a singlet FODO system, in which the magnets are set around the acceleration structures, is used because of the shorter intervals of the quads. Between the end of the FODO until the middle of Sector-3, triplets are located at various intervals as the positron emittance changes. From the latter part of Sector-3 to the end of Sector-5, triplets are located every two units (i.e. 19.2 m). The betatron wavelengths at the FODO system, the tapered and the constant interval regions are 4 ~ 8 m, 12 ~ 40 m and 80m respectively. On the other hand, when electrons are injected into the ring, the target is retracted and the electron beam passes through the positron focusing system. The focusing strengths are set for a betatron wavelength of about 160 m, since electrons have a small emittance and a large momentum. To show that the designed transport has sufficient acceptance, the beam envelopes were calculated by using the TRANSPORT code [6]. The results are given in Fig. 3-a for the region from the pre-injector to the 180° turn and in Fig. 3-b for the latter part. As it can be seen in the figures, the envelopes are well within the aperture of the accelerator.

Achromatic and Isochronous 180° turn

To keep the beam emittance and the bunch length small in passing the 180° turn, the deflecting system must be achromatic and isochronous. In the preliminary design, it comprises eight 22.5° deflecting sector magnets and seven quadrupole singlets interleaved in between. The focusing strengths of the quads are calculated using the TRANSPORT code to satisfy the conditions that the particle position, angle and the path length are independent of its energy in the first-order transfer matrix. The calculated beam envelopes are shown in Fig. 3. The energy spread is assumed to be $dE/E = \pm 1.5\%$. This shows that the aperture in the bending plane at the 180° turn must be greater than ± 20 mm for that energy spread.

Conclusion

The quadrupole focusing system layout for the KEKB injector was determined considering the beam emittance and the transport acceptance. The beam envelopes calculated with the TRANSPORT code are shown to be well within the accelerator aperture. Preliminary design of the 180° turn satisfies the achromatic and isochronous conditions.

References

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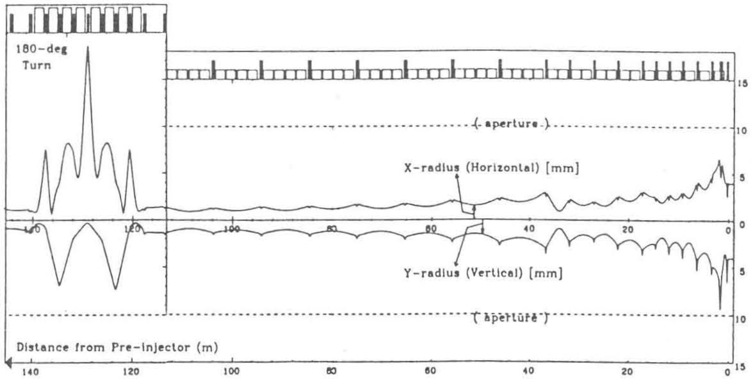

Fig.3-a Calculated beam envelopes from the pre-injector to the 180° turn

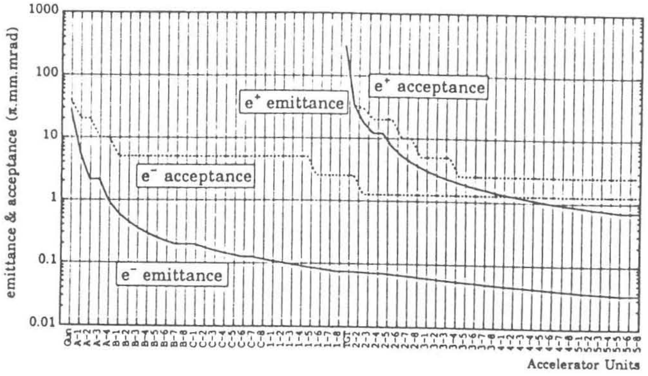

Fig.2 Expected beam emittances and designed transport acceptances

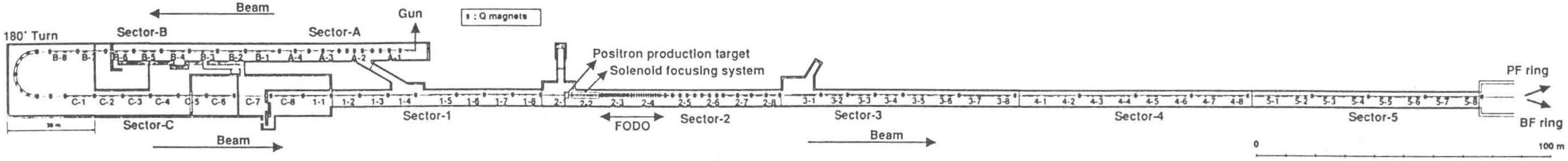

Fig.1 Layout of the KEK-B injector

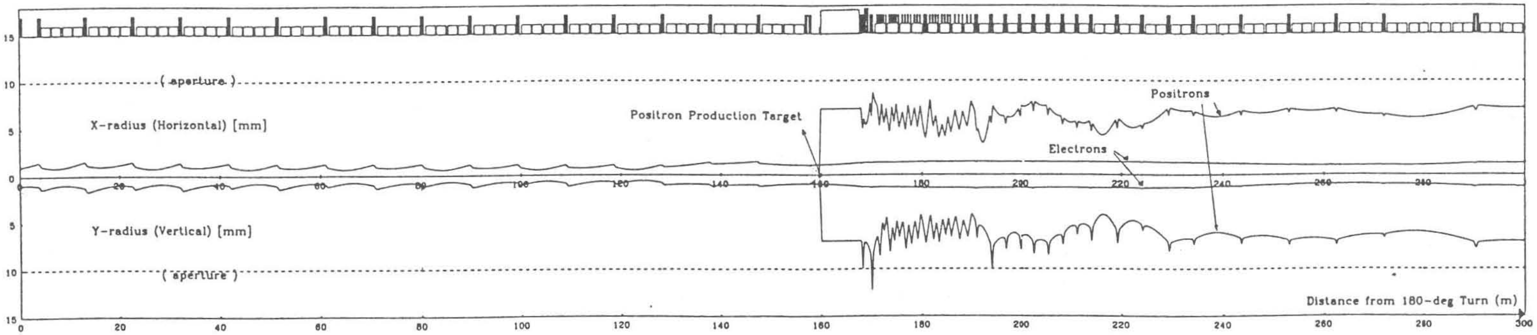

Fig.3-b Calculated beam envelopes after the 180° turn