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WAKE-FIELD ISSUES CONCERNING THE KEK B-FACTORY INJECTOR LINAC

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Abstract

In the KEK B-Factory (KEK-B) injector linac, it is required that a high-intensity, single-bunched electron beam be accelerated up to the conversion target (4 GeV) while maintaining good stability and quality of the beam for a large yield of positrons. In this connection, we have estimated both the longitudinal and transverse effects of a wake field concerning the KEK-B injector linac, especially focusing on the bunch-length dependence of the longitudinal effect and the injection tolerances and cavity misalignments of the transverse effect. By performing numerical calculations based on simplified models of wake-field effects, we obtained several constraints on the accelerator parameters, provided that a beam transport/monitoring system is well accommodated. Some problems concerning the stable acceleration of a single-bunched electron beam having a charge of several nano Coulomb are also discussed.

Introduction

A detailed investigation of wake-field issues regarding linac beam characteristics is indispensable for the KEK-B injector linac [1], since the energy spread and instability of a high-intensity primary electron beam for positrons may cause an emittance growth or a reduction in the positron yield at the conversion target. In the KEK-B injector linac, a single-bunched beam of about 10 nano Coulomb must be accelerated up to the conversion target (4 GeV) without any degradation of the beam quality in order to maintain a large positron yield (see Table 1).

Table 1
Parameters of Primary Electron Beam for Positrons

Beam Parameters	Designed Value
Acceleration Frequency	2856 MHz
Total Charge (Single Bunch)	10 nC (N=6×10^{10})
Acceleration Field	20 MV/m
Final Energy	≈ 4 GeV
Beam Size (Diameter)	0.6 mm @target

There are several key issues which determine the beam characteristics: the bunch length, the energy spread, acceleration phases, the average energy gain, injection tolerances and cavity misalignments. The longitudinal wake field causes an energy spread within a bunch as well as a decrease in the average energy, depending on the bunch length and the acceleration phase, while the transverse wake field induces a beam instability due to injection errors and cavity misalignments.

We report here on some results concerning the parameters of the KEK-B injector linac constrained by wake-field effects.

Longitudinal Wake-Field Effects

In order to estimate the longitudinal wake-field effects, we assume several definitions for beam parameters and a wake potential. The acceleration field is given by

$$E(t)=E_a(t)-E_b(t),$$

where

$$E_a(t) = E_a\cos(\omega t-\theta) \qquad \text{(acceleration field)},$$

$$E_b(t)=\int_0^{\infty} W(t')I(t-t')dt' \qquad \text{(longitudinal wake field) and}$$

$$q\equiv\int_{-\infty}^{\infty} I(t')dt' \qquad \text{(total charge)}.$$

The average energy and the energy spread are defined by

$$\langle E(t)\rangle \equiv \frac{1}{q}\int_{-\infty}^{\infty} E(t')I(t')dt'$$

and

$$\sigma_E^2\equiv\left\langle\left[E(t)-\langle E(t)\rangle\right]^2\right\rangle,$$

respectively. The charge distribution of the beam is assumed to be Gaussian,

$$I(t)=\frac{qc}{\sqrt{2\pi}\sigma_z}\exp\left(-\frac{c^2t^2}{2\sigma_z^2}\right),$$

where σ_z corresponds to the bunch length and c is the velocity of light. The wake potential was calculated using the TBCI code, and turned out to be approximated by

$$W(t)=A\exp\left[-\left(\frac{t}{B}\right)^n\right] \qquad (0\leq t\leq 20\text{ps}), \text{ where}$$

$$A=2.26\times10^{14} \quad \text{V/m/C},$$

$$B=6.13\times10^{-12} \quad \text{sec, and}$$

$$n=0.605,$$

which is equivalent to the formula obtained at SLAC [2].

Using these definitions, we calculated some of the longitudinal wake-field effects. The energy spread is plotted as a function of the bunch length in several cases of the total charge (Fig. 1), where the solid lines represent normal accelerations on the crest of the acceleration rf field, while the dotted lines indicate the so-called off-crest accelerations at the optimum phases. For a comparison, a case without wake-field effects is also shown. For the acceleration of a charge of 10nC, the optimum bunch length (σ_z) is about 1.5mm and the corresponding energy spreads (σ_E) are about ±1.2% for on crest and ±0.5% for off crest, both of which are well within the designed value of the transport parameters [3]. As a result, in the case of 10nC acceleration, it is not necessary to introduce the off-crest method, although the acceleration of a total charge of more than 10nC would require it.

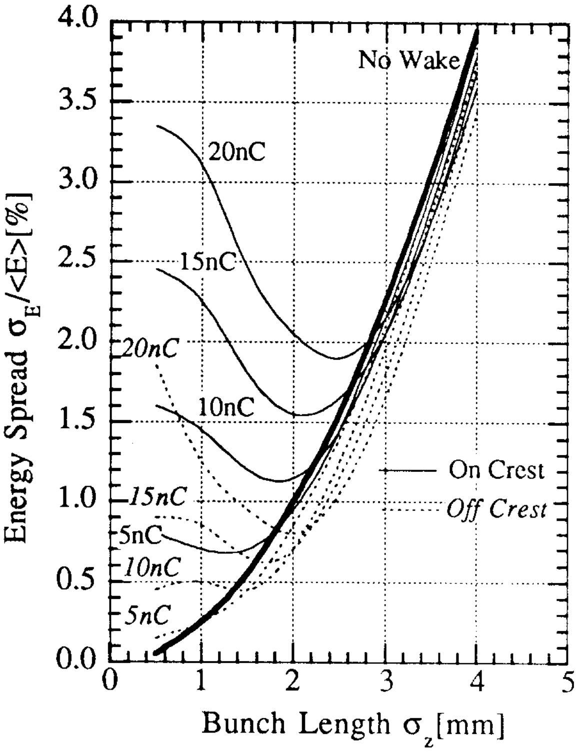

Fig. 1 Bunch-length dependence of the energy spread.

The average energy loss is also plotted in Fig. 2 in the same manner as in Fig. 1. It is shown that the beam-loading effect is about -3% for 10nC on the crest acceleration and -4% for off crest at a bunch length (σ_z) of 1.5mm, which can be easily recovered by the designed margin of the rf-power system [1]. Fig. 3 shows the bunch-length dependence of the optimum off-crest phases.

Longitudinal wake-field effects involve other problems, such as a bunching limit in the buncher section and bunch lengthening in the first several focusing stages of low-energy positrons. These problems are to be discussed elsewhere [4].

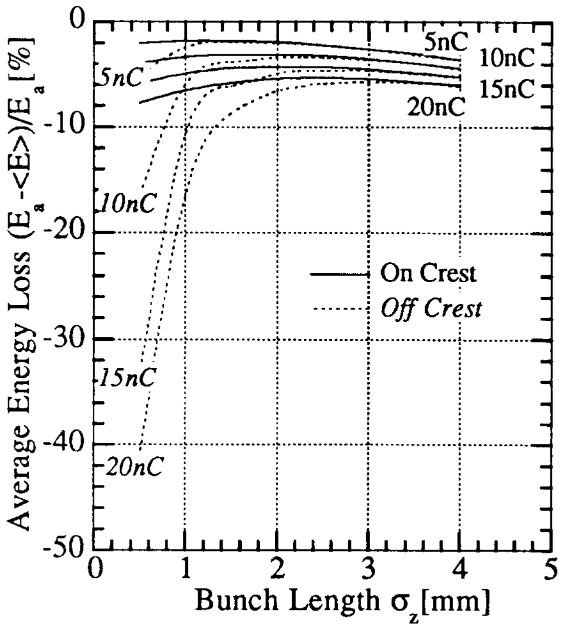

Fig. 2 Average energy as a function of the bunch length.

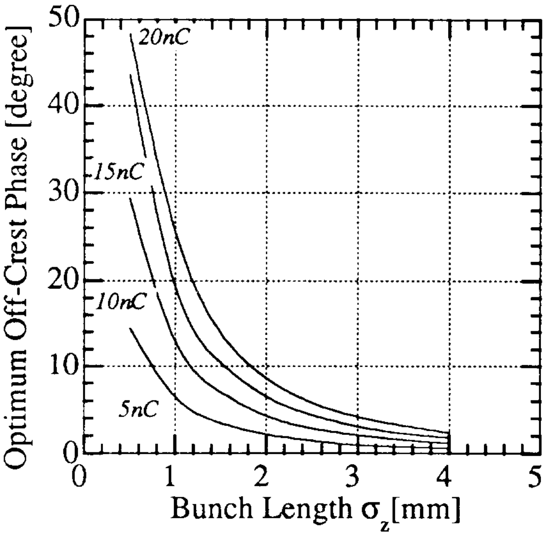

Fig. 3 Optimum off-crest phase as a function of the bunch length.

Transverse Wake-Field Effects

The transverse wake-field effects were examined in two categories: injection tolerances and cavity misalignments, which were evaluated using a smooth-focusing model for the following equations of motion:

$$\frac{d}{ds}\left(\gamma(s,z)\frac{d}{ds}x(s,z)\right)+\gamma(s,z)k(s,z)^2x(s,z)$$

$$=r_0\int_z^\infty dz'\rho(z')W(z'-z)x(s,z'),$$

where

$x(s,z)$: transverse displacement of the particles in the bunch (z) at the distance (s)
$\gamma(s,z)$: energy Lorentz factor of the particles
$k(s,z)$: betatron wavelength
r_0: classical electron radius
$\rho(z)$: linear number density of the particles
$W(z)$: transverse wake field

The solutions are given by Chao, Richter and Yao [5] based on the following assumptions: (1) a uniform charge distribution of the bunch, (2) a short bunch length and (3) no energy spread / the same betatron wavelength within the bunch.

Using these solutions and Table 2, which gives the beam parameters needed for calculations of the transverse effects, we estimated the injection tolerances and cavity misalignments concerning wake-field effects.

Table 2
Beam Parameters for Calculations of the Transverse Wake-Field Effects

Injection Energy	100 MeV
Final Energy at the Target	4 GeV
Acceleration Gain	20 MeV/m
Acceleration Length	200 m
Betatron Wavelength	40 m
Total Charge	10 nC
Amplitude of Wake Field	3×10^{15} V/C/m^2 (3×10^5 1/m^3)
Bunch Length (σ_z)	1.5 mm (5 psec)

Injection Tolerances

The ratios of the final displacements of the beam to its injection errors within a bunch are shown in Fig. 4, where the solid line indicates the 10nC acceleration case, while the dotted line shows the 20nC acceleration case. This figure represents a transverse bunch-shape deformation due to injection errors. Assuming a beam size of 0.6mm at the target (Table 1), we calculated the following constraints on the injection errors:

$$x_{\text{injection}} \ll 0.5 \text{ mm for } 10 \text{ nC}$$

and

$$x_{\text{injection}} \ll 0.2 \text{ mm for } 20 \text{ nC},$$

which determine the required resolution of the beam position monitors. Using appropriate monitors and eliminating injection errors by using steering coils, one can suppress any transverse effects due to injection errors.

Cavity Misalignments

Assuming one hundred accelerating tubes for a 200-m acceleration length, we obtained the following cavity misalignment errors:

$$d_{\text{rms}} \ll 1.2 \text{ mm for } 10 \text{ nC}$$

and

$$d_{\text{rms}} \ll 0.4 \text{ mm for } 20 \text{ nC},$$

which should be accomplished using a new alignment system which is under construction.

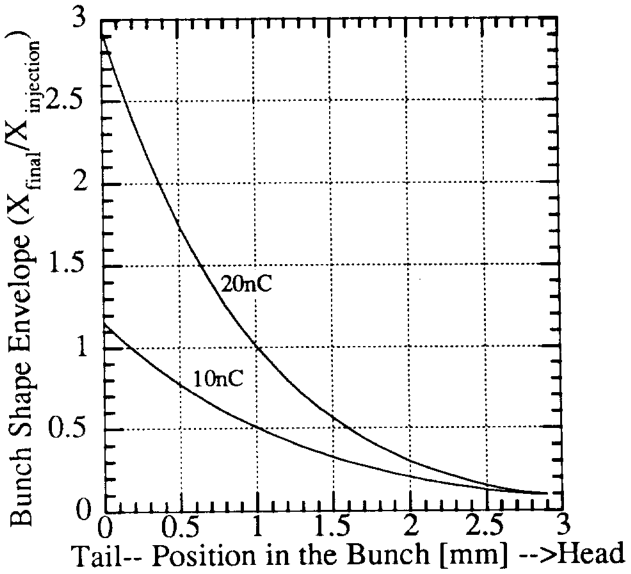

Fig. 4 Bunch-shape deformation due to injection errors.

Conclusions and Discussions

Various wake-field issues concerning the KEK-B injector linac were considered by using simple models regarding the wake fields. A rough estimation showed that the designed total charge of 10 nC is a critical value from the wake-field point of view, although it seems that no special cures for wake-field effects are needed.

References

[1] A. Enomoto et al., "Re-formation of the PF 2.5GeV Linac to 8 GeV", these proceedings.
[2] P. B. Wilson, "High energy electron linacs: Applications to storage ring RF systems and linear colliders", SLAC-PUB-2884 (1982).
[3] T. Kamitani et al., "Design of the beam transport system of the KEK B-Factory Injector Linac", these proceedings.
[4] S. Ohsawa et al., "High intensity single-bunch beam of the KEK2.5GeV Linac", these proceedings.
[5] A. W. Chao et al., "Beam emittance growth caused by transverse deflecting fields in a linear accelerator", Nucl. Instrum. Methods, 178, 1 (1980).