EMITTANCE PRESERVATION IN SUPERKEKB INJECTOR

S. Kazama*, M. Satoh, H. Sugimoto, M. Yoshida, Y. Ogawa
High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, 305-0801, Japan

Abstract

Injector linac at KEK is now under the way to produce high current and low emittance beams for SuperKEKB. The target luminosity for SuperKEKB is 40 times higher than that of KEKB. A short-range transverse wakefield and a dispersive effect at the linac cause an emittance growth, and a longitudinal wakefield effect enlarges an energy spread of the beams. In this paper, we presented simulation studies concerning the emittance preservation and the energy spread issues. As a candidate for the mitigation of the emittance dilution originating from the transverse wakefield, a so-called "offset injection" method using steering coils is considered. It is demonstrated that the offset injection remarkably improves the emittance preservation.

INTRODUCTION

SuperKEKB is an electron-positron collider with an energy of 7 GeV and 4 GeV, respectively. The target luminosity is $8{\times}10^{35}\mathrm{cm}^2\mathrm{s}^{-1}$, which is 40 times higher than that of KEKB [1]. SuperKEKB main ring therefore requires a high current and low emittance beam. These parameters are summarized in Table 1. In order to meet the requirement, photo-cathode RF guns are now installed at the injector linac for the electron beam. For the production of a low emittance positron beam, a damping ring is now under construction. Since the target emittance is quite small compared to that of KEKB, much more attention should be paid to the emittance growth through the linac. The Short-range wakefield and the dispersive effect are considered to be the major sources of the emittance dilution. In this paper, we report on a design study on SuperKEKB injector for high current, low emittance, and low energy spread beams. We mainly report on simulation studies concerning the emittance preservation issues and how to suppress the increase of the energy spread. All simulation presented in this paper is performed with elegant [2].

Table 1: Required parameters for SuperKEKB

	Phase 2 (e^+/e^-)	**Phase 3** (e^+/e^-)
Bunch charge [nC]	2 / 2	4 / 5
Vertical emittance [mm mrad]	20 / 20	20 / 20
Horizontal emittance [mm mrad]	100 / 50	100 / 50
Energy spread [%]	0.1	0.1

* kazama@post.kek.jp

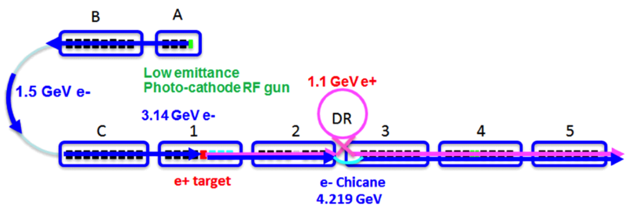

Figure 1: Schematic of SuperKEKB injector linac.

TRACKING SIMULATION

Figure **1** shows a schematic of SuperKEKB injector linac. The linac is mainly composed of 9 sections. In this paper, simulation is performed from C-sector to 5-sector for sim-plicity.

Condition of simulation

The initial particle distribution in the longitudinal direction at the C-sector is a Gaussian of 10 ps bunch length (FWHM) with 2 or 5 nC charge and 1.5 GeV energy. The distributions of transverse phase space and energy spread are both assumed to be Gaussian. The initial emittance in the horizontal and vertical directions and the energy spread are set to be 10 mm mrad and 0.1 %, respectively. Longitudinal monopole and transverse dipole wakefield are incorporated in the simulation with an analytical expression of the wake functions [3]. Long-range wakefield effects are not taken into account in the simulation. The electron beam is approximated by 10^5 macro particles. For the study of the effect of misalignment on the emiitance growth, alignment errors for quadrupole magnets and acceleration tubes are considered, and their distributions are assumed to be Gaussian.

EMITTANCE PRESERVATION

Short-Range Wakefield and Misalignment

When a bunch of electron beam passes through a misaligned accelerating structure, the head particles in the bunch will interact with the beam pipe and leave a wakefield to the tail particles. The induced wakefield can deflect the trailing particles further away from the axis, resulting in an increase of the projected beam emittance. A small amount of misalignment and a short bunch length can reduce the transverse wakefield strength. However, the short bunch length causes the strong longitudinal wakefield, resulting in a large energy spread. Therefore, the bunch length has to be optimized with a detailed simulation. The dependence of the bunch length on the energy spread will be discussed in the next section. To achieve the required emittance, the magnitude of the misalignment must be kept as small as possible. Figure. 2 shows a simulated vertical emittance at the end of 5-sector as a function of the magnitude of local misalignment when the charge of the electron beam is 5 nC. It shows that the vertical emittance of 20 mm mrad can be realized if the magnitude of the misalignment is smaller than 0.1 mm in sigma.

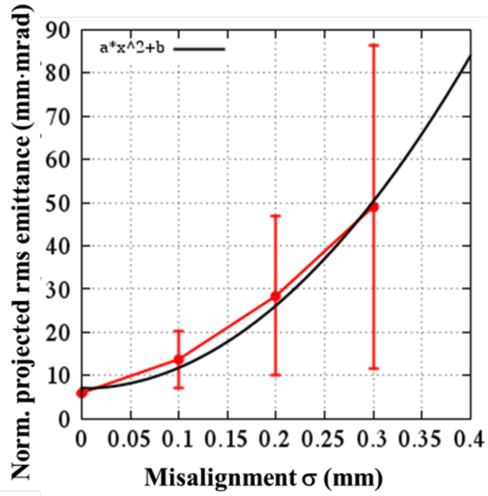

Figure 2: Vertical emittance at the end of 5-sector as a function of the magnitude of misalignment.

In the SuperKEKB injector linac, the local alignment of the accelerator structures at the 3, 4, and 5-sector has been performed with a laser tracker during summer shutdown in 2014 [4]. As shown in Fig. 3, measured local alignment errors in the horizontal and vertical directions are estimated to be about 15 μm and 40 μm, respectively. Therefore, the initial goal of 100 μm seems to be already achieved. Systematic uncertainties on the measurement are now under investigation. The most important error is expected to come from the uncertainty of the alignment of the girders on which accelerator structures are placed.

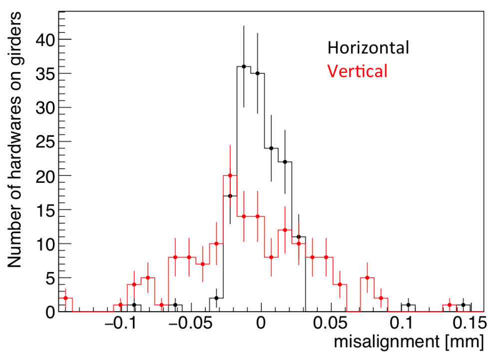

Figure 3: Measured misalignment of the accelerator structures on the girders in the horizontal (black) and vertical (red) direction.

Offset Injection

As discussed in the previous section, accelerator elements cannot be perfectly aligned. Hence, even when the beam is injected without an offset, the misalignment will induce the transverse wakefield. In order to reduce the emittance growth, a compensation method ("offset injection") has been investigated in this paper. In the actual experiment, this can be performed by adjusting the current of steering coil. Electron beams are then injected into the next section with a certain kick angle and a certain offset. The kick angle can be tuned in units of 0.1 μrad, and the effect originating from the instability of a power source is estimated to be negligible. We simulated the effect of the offset injection in the case of Phase 2 and 3 using a lattice with an alignment error of 0.1 mm in sigma. Figure 4 and 5 show the vertical emittance at the end of 5-sector as a function of the offset and the kick angle when the beam charge is 2 and 5 nC, respectively. In both cases, optimal offsets and kick angles are estimated to be relatively small, which means that it is necessary to control the orbit stably in a high precision. In the case of 2 nC, a large number of combinations of offsets and kick angles satisfy the requirement in Phase 2. On the other hand, only a few parameters satisfy the requirement in the case of 5 nC, therefore the orbit control in Phase 3 will be quite challenging.

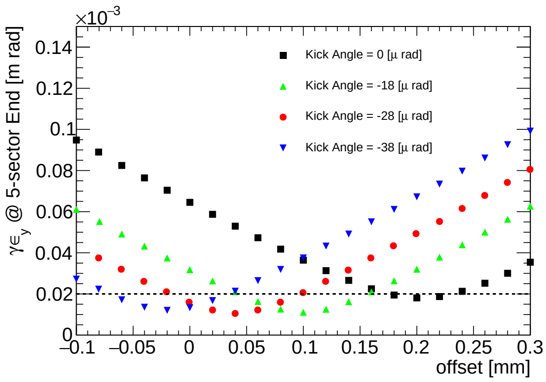

Figure 4: Vertical emittance as a function of the offset and the kick angle when the beam charge is 2 nC.

ENERGY SPREAD

As another possible way to mitigate the emittance degradation, a bunch compression using J-Arc section is now under investigation [5]. Since the transverse wakefield effect can be reduced by shorter bunch length, a bunch compression system with non-isochronous J-arc could be a solution to achieve a lower emittance. However, the shorter bunch length causes the stronger longitudinal wakefield, resulting in a large energy spread. Therefore, it has to be well studied with detailed simulation. In this section, the relation between the bunch length and the energy spread is investigated. In the following simulation, the initial energy spread is set to be 0 to confirm how much energy spread is induced.

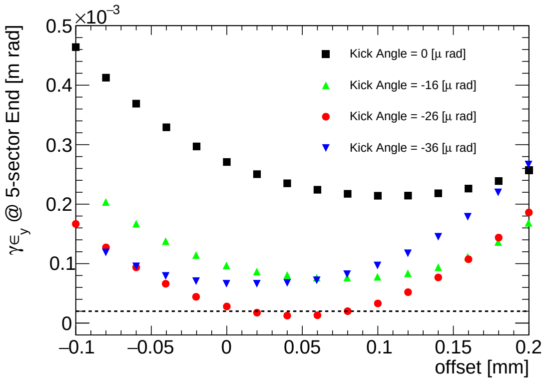

Figure 5: Vertical emittance as a function of the offset and the kick angle when the beam charge is 5 nC.

Figure 6 shows the energy spread at the end of 5-sector as a function of the bunch length with on-crest RF phase for various types of longitudinal beam distributions. Gaussian and rectangular shapes are considered as a longitudinal beam distribution in this simulation, and the bunch length for a rectangular distribution is defined by its full width. As shown in the figure, there is no solution which satisfies the requirement in both Phase 2 and 3.

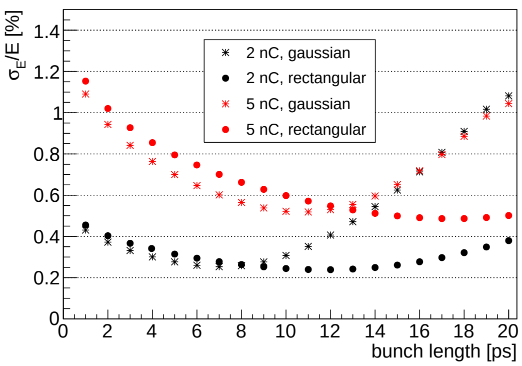

Figure 6: Energy spread at the end of 5-sector as a function of the bunch length with on-crest RF phase.

In order to suppress the energy spread, the "off-crest" method is studied in this paper. Since the beam energy in SuperKEKB is much smaller than that in KEKB, there is a 5 % margin in the accelerating voltage, which means that we could change the RF phase up to 20 degree. Figure 7 shows the energy spread as a function of the bunch length with optimal RF phase. In the case of 2 nC, the energy spread of 0.1 % can be achieved even when the Gaussian beam distribution is assumed. However, in the case of 5 nC, only rectangular beam distribution satisfies the requirement in Phase 3. Therefore, it is crucial to make such an optimal beam shape, and the study concerning a laser pulse shaping is now on-going [6].

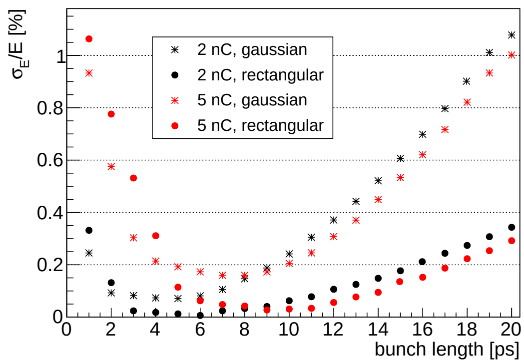

Figure 7: Energy spread at the end of 5-sector as a function of the bunch length with optimal RF phase.

CONCLUSION

Design study on the KEK injector linac upgrade is reported focusing on numerical simulation for the emittance preservation and the beam energy spread. As a candidate for the mitigation of the transverse wakefield effects, the offset injection method using steering coils is considered. It is numerically shown that the requirement in Phase 2 and 3 can be satisfied with this method, although it is necessary to control the orbit stably in a high precision at Phase 3. The energy spread of 0.1 % also can be achieved if beams are placed on the optimal off-crest RF phase and the longitudinal beam distribution is rectangular. An experimental demonstration of the offset injection method and more systematic studies between the emittance preservation and the energy spread are under study.

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