EMITTANCE GROWTH BY MISALIGNMENTS AND JITTERS IN SUPERKEKB INJECTOR LINAC

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Abstract

SuperKEKB injector linac have to transport high-charged beam with low emittance to SuperKEKB ring for high luminosity, 8×10^{35}. For the low emittance, photocathode RF gun was adopted as electron source. One of the main reason of the beam emittance blow-up electron linac is generally induced by wakefield in acceleration cavities. A charged beam with a offset from a center of a cavity is affected by the wakefield depending on the offset size in the acceleration cavity and the beam emittance is increased. This emittance blow-up can be eliminated by appropriate steering magnet control so as to cancel the wake effect in the acceleration cavity. We perform particle tracking simulation with some misalignments and beam jitter. Emittance growth by the misalignments and the beam jitter is evaluated in this report.

INTRODUCTION

SuperKEKB is electron-positron collider for particle physics in KEK. Design luminosity of the SuperKEKB is 8×10^{35}, which is 40 times higher than that of KEKB [1]. For the high luminosity, high quality beam is necessary for the injector linac. Phase 1 of SuperKEKB project started from Feb. 2016. Various devices and software operation check, and vacuum hardening are going.

Figure 1 shows schematic layout of the linac. The linac is composed of sector A, B, J-ARC, C, and 1~5. Normalized emittance less than 20 mm.mrad at the end of linac is required in the final phase, which will start from Oct. 2018. The linac has two kinds of electron gun: thermal gun for high-current electron beam (10 nC) for positron generation and photocathode RF gun for low emittance electron beam (5 nC). Positron beam is accelerated up to 4 GeV and transported to LER(Low Energy Ring). Low emittance electron beam (5 nC) is accelerated up to 7 GeV and transported to HER(High Energy Ring). Two bunch operation will be performed at 50 Hz with 96 ns bunch space. Positron beam emittance for LER is reduced by DR (Damping Ring), which is placed between section 2 and 3 and will be operated from 2017. There is not major emittance reduction mechanism about electron beam for HER because there is not DR for electron beam. Emittance preservation of the electron beam in the SuperKEKB injector linac was studied by Ref. [2–4]. The emittance preservation is desired, however not only misalignments of accelerator components but also various jitters cause emittance growth. We evaluate the emittance growth by realistic misalignments of quadrupole magnet and acceleration cavity and by realistic jitters of quadrupole and steering magnetic force and beam position with current lattice data (Feb. 2016).

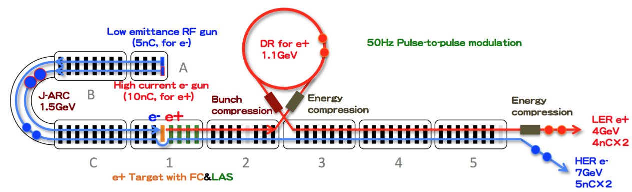

Figure 1: Schematic layout of the SuperKEKB injector linac.

SIMULATION SETUP

We performed particle tracking simulation for SuperKEKB linac from sector C to sector 5. Transverse and longitudinal wake field in acceleration cavity are taken into account using an analytical short range wake functions [5]. Only short range wake field is treated because bunch space of two bunch operation is 96 ns and the space is long enough to ignore middle-range wake field in our S-band accelerator cavity. In this paper, all simulations are performed by the Strategic Accelerator Design program [6]. Procedure of low emittance tuning is as following.

1. Orbit correction at BPM.

2. Four steering tuning at the front of sector C for low emittance tuning (offset injection).

In the linac, reference point of BPM is calibrated to center of quadrupole magnet by Quad-BPM method [7]. In the simulation, BPM have same misalignment as that of nearest quadrupole magnet. Offset injection is one of the effective method to search an orbit for low emittance [8]; Orbit search so as to cancel wake effect in acceleration cavity by steering magnet is performed to minimize emittance at the linac end, where wire scanner is placed. Acceleration cavities have same misalignment values if they are placed on same frame. Doublet quadrupole magnets also have same misalignment values. Table 1 is basic parameters of this simulation.

EMITTANCE GROWTH

Target emittance is less than 20 mm.mrad at the end of linac. Emittance growth compensation by offset injection. Misalignments of quadrupole magnets and acceleration cavities have gaussian distribution. Definition of emittance in this paper is RMS emittance,

$$\epsilon_x = \gamma\beta\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}, \quad (1)$$

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Table 1: Basic Parameter Set. Aperture values indicate the radius. δ is relative momentum deviation.

Parameter	Value	Unit
Initial emittance	10	mm.mrad
Initial charge	5	nC
Initial σ_z	3/2.35	mm
Initial δ	0.004	-
# of initial particles	40000	-
Distribution	Gauusian	-
S-band accelerator aperture	10	mm

where γ and β are Lorentz factor and Lorentz β, respectively. Realistic limited steering magnetic force is taken into account for all simulation in this paper.

Figure 2 is one of the simulation result with 0.3mm RMS misalignment. Blue and red point show horizontal and vertical parameters, respectively. From the top of this figure, emittance, # of transported particles, orbit, root of beta function, dispersion, relative momentum deviation, bunch length, misalignments of quadrupole magnets, misalignments of acceleration cavities, and K value of steering magnet, respectively. From the center of sector 1, emittances increase temporally since there is chicane in the place.

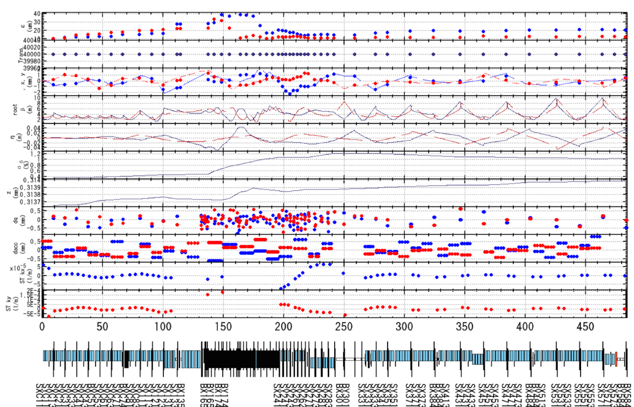

Figure 2: An example of beam parameters from sector C~5 with 0.3mm RMS misalignment of quadrupole magnets and acceleration cavities.

Misalignments

60 kinds of random misalignments (quadruple magnets and acceleration cavities) in each RMS misalignment (0.1mm, 0.2mm, and 0.3mm) are simulated. In this subsection, jitters are not taken into account. Figure 3 shows horizontal vs. vertical emittance at the linac end for 60 random seed. In the case of 0.3mm misalignment, there are over 20 mm.mrad emittance, and the probability is 9/60. While, there is not over 20 mm.mrad emittance in 0.1mm and 0.2mm RMS misalignment. Less than 0.2mm RMS misalignment is desirable from this result and it can be realized by existing measurement devices.

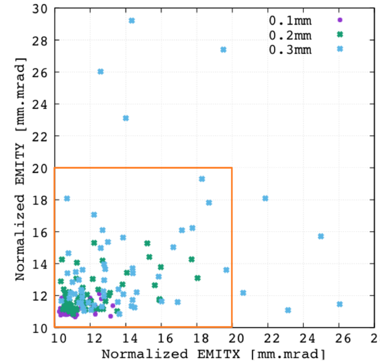

Figure 3: Emittance growth at the linac end for 60 random seed in each RMS misalignment.

Misalignments and Jitters

100 kinds of random jitters (K value jitters of quadrupole and steering magnets, beam position jitter) for the each 60 kinds of misalignments in each RMS misalignment are simulated. Amplitudes of the jitters in the simulation are following:

- K value jitter / K value= 0.2% (peak-to-peak).
- beam position jitter = 100μm (gaussian).

These amplitudes are realistic values in the linac. In Fig. 4, black points shows emittance growth averaged for 100 kinds of jitters (K value jitters of quadrupole and steering magnets). There are 60 black points in the each RMS misalignments. The horizontal axis shows average of horizontal and vertical emittance at the linac end. Red line shows emittance growth averaged for 60 kinds of misalignments and for 100 kinds of jitters in the each RMS misalignment. Yellow points shows emittance growth without the jitters. This figure shows emittance growth by the jitters of the K values is smaller than 1 mm.mrad.

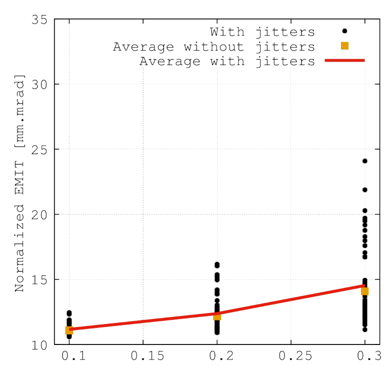

Figure 4: Emittance growth averaged for 100 kinds of jitters (K value) about 60 misalignment.

In Fig. 4, black points shows emittance growth averaged for 100 kinds of jitters (K value jitters of quadrupole and steering magnets + beam position jitter) in each 60 kinds of misalignments. Red and yellow points in Fig. 5 show emittance growth in the same manner as Fig. 4. From Fig. 4 and Fig. 5, beam position jitters cause constant emittance growth, about 5 mm.mrad. From the results, it is necessary for less than 20 mm.mrad emittance to be satisfy following requirements at least: both less than 0.2mm RMS misalignment and less than 100μm beam position jitter. In this simulation, beam angle jitter is not taken into account, therefore the RMS misalignments or the beam position jitter tolerance may have to be smaller.

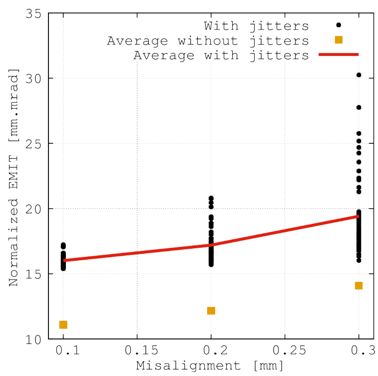

Figure 5: Emittance growth averaged for 100 kinds of jitters (K value and beam position) in each 60 kinds of misalignments.

Measured Misalignments

In the linac, frame position is measured by Si Photo-Diode(PD), which is placed at the start and end of the frames. Figure 6 shows frame position measured in Jun. 21, 2016. The horizontal axis shows longitudinal length from the sector C to sector 5. Blue and red points show horizontal and vertical frame positions, respectively. RMS horizontal and vertical misalignments are 0.16mm and 0.26mm, respectively.

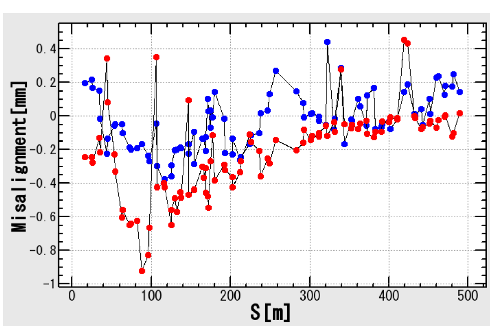

Figure 6: Frame position data measured by Photo-Diode.

Emittance growth is simulated using measured misalignment. Position changes of the acceleration cavities on the frame are less than that of frame itself; σ_{ACC} =0.1mm as RMS misalignments of acceleration cavities on the frame is assumed. Total RMS misalignments of acceleration cavities are following:

$$\sigma_{total} = \sqrt{\sigma_{frame}^2 + \sigma_{ACC}^2}, \tag{2}$$

where σ_{frame} is RMS frame position. As RMS misalignment of quadrupole magnet misalignment, σ_Q =0.2mm is assumed. The result of emittance growth about 100 random seed for σ_{ACC} and σ_Q is shown as Fig. EGMM. Almost all of the case satisfy less than 20 mm.mrad emittance. Evaluation of emittance growth by jitters are now going.

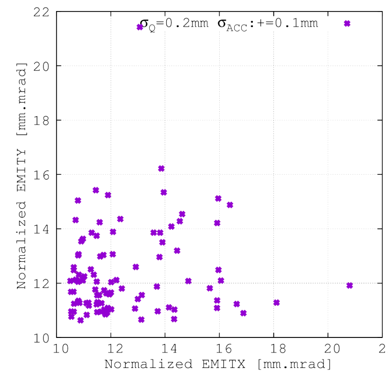

Figure 7: Emittance growth for 100 kinds of misalignments measured by Photo-Diode.

SUMMARY

Particle tracking simulation with misalignments and beam jitters is performed. From the simulation results, it is necessary for less than about 20 mm.mrad emittance at the linac end to satisfy following conditions at least: less than 0.2mm RMS misalignments of quadrupole magnet and acceleration cavity, and less than about 100μm beam jitter (without angle jitter). Emittance growth by relatively 0.2% jitter about magnetic force of quadrupole and steering is relatively small in the linac, less than 1 mm.mrad emittance growth. On the other hands, beam position jitter 100 μm cause about 5 mm.mrad averaged emittance growth. In this paper, beam angle jitter is not taken into account, therefore the RMS misalignments or the beam position jitter tolerance may have to be smaller. The beam jitter source searching is now going.

ACKNOWLEDGEMENT

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REFERENCES

[1] KEKB Design Report, KEK Report 95-7.

[2] L. Zang et al., in *Proc. of IPAC'11*, San Sebastian, Spain, paper MOPS058, p. 739.

[3] H. Sugimoto *et al.*, in *Proc. of IPAC'12*, New Orleans Louisiana, USA, paper TUPPC021, p. 1206.

[4] S. Kazama *et al.*, in *Proc. of IPAC'15*, Richmond, VA, USA, paper MOPWA053, p. 239.

[5] K. Yokoya, "Short-range wake formulas for infinite periodic pill-box", 1998, unpublished.

[6] Strategic Accelerator Design(SAD) home page, `http://acc-physics.kek.jp/SAD/`

[7] M. Masuzawa *et al.*, in *Proc. of EPAC'00*, Austria, Vienna, p. 1780.

[8] A.W Chao, B. Richter, and C.-Y. Yao, in *Nucl. Instr. Meth. A*, vol. 178, p. 1, 1980.

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