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BEAM PHASE SPACE JITTER AND EFFECTIVE EMITTANCE FOR SuperKEKB INJECTOR LINAC*

Y. Seimiya†, N. Iida, T. Kamitani, M. Satoh, KEK, Ibaraki, Japan

Abstract

In SuperKEKB linac, stable high charged low emittance beam is necessary. Transported beam to SuperKEKB Main Ring (MR) must be stable to the extent that the beam can be injected inside MR acceptance. SuperKEKB requirement must be satisfied for emittance including beam phase space jitter, called as effective emittance. Large amplitude beam position jitter has been measured at linac end. We evaluated that the effect of the beam position jitter to effective emittance and investigated the cause of the beam position jitter.

INTRODUCTION

SuperKEKB is e+/e- collider for high energy particle physics in KEK. Design luminosity of the SuperKEKB is 8×10^{35}, which is 40 times higher than that of KEKB achieved [1]. This high luminosity can be realized by twice current and one-twentieth beam size compared with that of KEKB. For the high luminosity, high intensity low emittance beam is necessary for the injector linac. If beam phase space is larger than SuperKEKB ring acceptance, the particles over the acceptance are lost and lifetime of the beam in the ring become short and luminosity goes down. Therefore, we have to transport high charged low emittance beam to SuperKEKB ring.

Phase 2 commissioning of SuperKEKB project started from Spring 2018. Collision and luminosity tuning is under going in May 2018 as mentioned reference [2]. Physics run is planned in the phase 3 from Winter 2018. Our target values of the phase 2 and phase 3 are shown as Table 1.

Schematic layout of the linac is shown as Fig. 1. The linac is composed of sector A, B, J-ARC, C, and 1~5. Normalized horizontal/vertical emittance less than 40/20 µm at the end of linac is required in the phase 3. The linac has two kinds of electron gun: thermionic gun for high-current electron beam for positron generation and photocathode RF gun for low emittance electron beam. Positron beam is accelerated up to 4 GeV and transported to LER (Low Energy Ring). Low emittance electron beam 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, which is placed between sector 2 and sector 3. 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. [3–5]. A charged beam with an offset from a center of cavity is affected by the wakefield depending on both the offset size in the cavity and longitudinal particle position in the beam. The wakefield causes emittance growth. This growth can be suppressed by appropriate orbit control so as to cancel the wakefield effect of the cavities in total. However not only misalignments of accelerator components but also beam variation cause emittance growth statistically, which simulation was performed in the reference [6].

* This work is supported by JSPS KAKENHI Grant Number 16K17545.
† yuji.seimiya@kek.jp

Table 1: Target Values of Linac for SuperKEKB

	H/V Emittance	Charge	Energy Spread
Phase 2	150/150 µm	1 nC	0.1%
Phase 3	40/20 µm	4 nC	0.07%

Transported beam to MR must be stable to the extent that the beam can be injected inside MR acceptance. SuperKEKB requirement must be satisfied for emittance including beam phase space jitter, called as effective emittance. We evaluate the emittance growth by beam phase space jitter and investigate the jitter source.

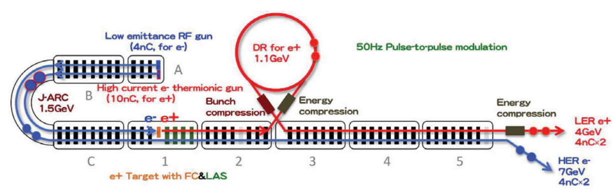

Figure 1: Schematic layout of the SuperKEKB injector linac.

EFFECTIVE EMITTANCE AND JITTER EMITTANCE

To evaluate the emittance growth by beam phase space jitter, we introduce following effective emittance,

$$\epsilon_{eff} = \sqrt{< X^2 >< X'^2 > - < XX' >^2}. \quad (1)$$

$$= \sqrt{\epsilon_0^2 + \epsilon_j^2 + 2\epsilon_0\epsilon_j \frac{\gamma_0\beta - 2\alpha_0\alpha + \beta_0\gamma}{2}} \quad (2)$$

$$= \sqrt{\epsilon_0^2 + \epsilon_j^2 + 2\epsilon_0\epsilon_j B_{mag}}. \quad (3)$$

$$X = x + \Delta x, \;\; X' = x' + \Delta x', \quad (4)$$

$$\epsilon_0 = \sqrt{< x^2 >< x'^2 > - < xx' >^2}, \quad (5)$$

$$\epsilon_j = \sqrt{< \Delta x^2 >< \Delta x'^2 > - < \Delta x \Delta x' >^2}, \quad (6)$$

where ϵ_0 and ϵ_j are nominal emittance and emittance converted beam phase space jitter (jitter emittance), respectively. B_{mag} shows mismatch between measured Twiss parameter and that of design. The value equal to or larger than 1. If $B_{mag} = 1$, there is not mismatch and effective emittance equal just nominal emittance plus jitter emittance. B_{mag}

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is about 1 ~ 2 in usual linac operation, which is measured by wire scanner. Assuming that beam position and transfer matrix between two BPMs are identified, beam angle can be derived. Jitter emittance can be derived from the beam position jitter and beam angle jitter.

RESULTS

We measured beam position jitter at BPM (beam position monitor) in the linac. Figure 2 shows measured beam position jitter and jitter emittance in the linac. Horizontal axis shows beam line position (m) from after the electron gun. Position jitter is standard deviation of measured beam position. Around the 140 m point of the figure, there is J-ARC section. Though the section is dispersive, beam energy jitter is converted to beam position jitter in this section. Dispersion was 0.8 m and position jitter was about 360 μm at the center of this section, then energy jitter was about 0.045%. After the J-ARC and positron generation target placed in about 290 m point, beam position jitter and jitter emittance was enlarged. At the end of linac, horizontal/vertical jitter emittance was about 27/7 μm. Though target value of the horizontal/vertical emittance in phase 3 is 40/20 μm, the effect of jitter emittance on effective emittance was very large. Figure 3 shows beam phase space jitter at before, after the target, and linac end. After the target, jitter emittance was clearly increased.

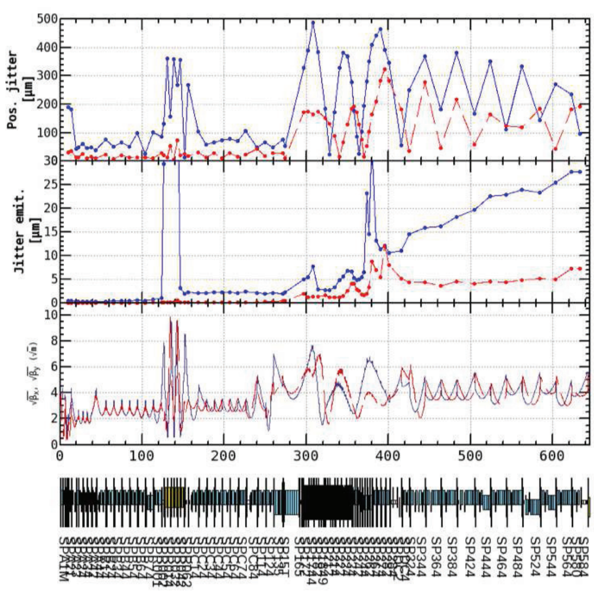

Figure 2: Measured beam position jitter and jitter emittance in the linac. The electron beam was 1 nC and generated by RF gun.

Figure 4 shows dispersion measurement result. Very large dispersion leak was measured. Quadrupole magnets in the J-ARC section was tuned to suppress the dispersion. After the dispersion suppression tuning, dispersion leak became small as shown Fig. 5. Measured beam position jitter and jitter emittance after dispersion suppression is shown as Fig. 6. By dispersion suppression, beam position jitter

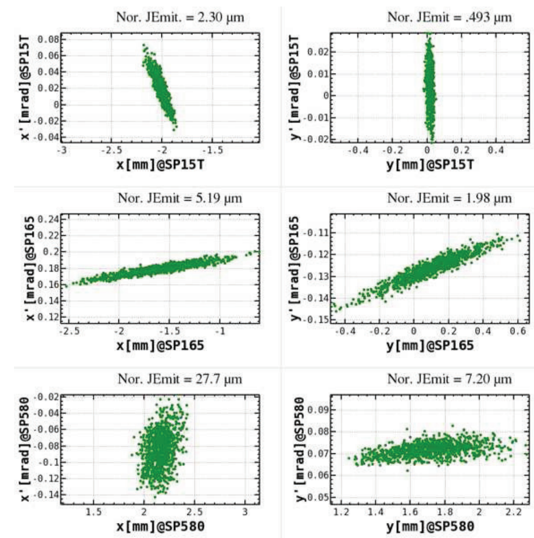

Figure 3: Beam phase space jitter at before, after the target, and linac end.

and jitter emittance were reduced. Horizontal/vertical jitter emittance at the end of linac was 1.8/0.9 μm. Under 1 nC beam operation, effect of the jitter emittance on effective emittance is small.

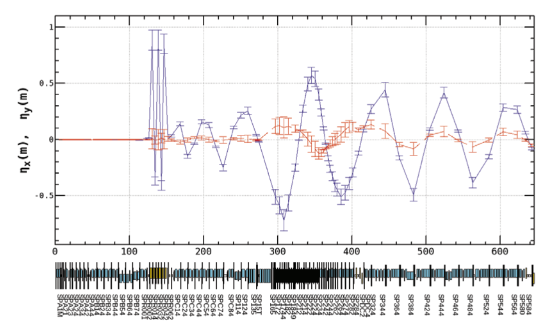

Figure 4: Dispersion measurement before the dispersion suppression.

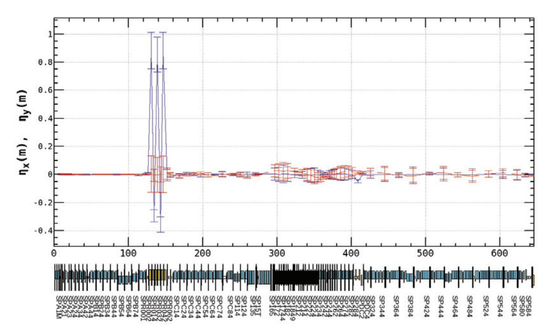

Figure 5: Dispersion measurement after the dispersion suppression.

Though jitter emittance become small by dispersion suppression, enhancement of the jitter emittance still remain at before and after the target. Enhancement factor, which is the ratio of beam position jitter after to before the target, is not changed remarkably by dispersion suppression. Around the

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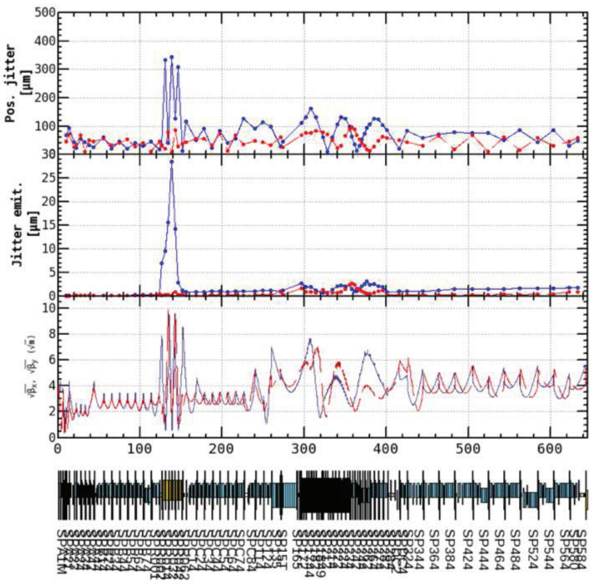

Figure 6: Measured beam position jitter in the linac after dispersion suppression. The electron beam was 1 nC and generated by RF gun.

target, there are some components which may influence the jitter; flux concentrator, solenoid, bridge coil, pulsed magnet, and chicane. We turned off the all of the components and measured the jitter, however there was no noticeable differences. Electron beam for LER hits the target, while electron beam for HER pass through the target hole (ϕ2mm). In case of positron after the target, there is not enhancement of the jitter. Then, the target hole was suspected as the jitter source.

Simulation analysis was performed by CST studio [7]. Figures 7 and 8 show simulation result of transverse and longitudinal wake potential induced by positron generation target, respectively. As distance between the beam position and the center of the target increase, transverse wake potential increase nonlinearly. While, longitudinal wake is independent of beam position from the center of the target hole. Even beam pass through outer side of the hole, the effect on the enhancement factor is too small to explain the measurement as far as design beta function or gaussian beam is assumed.

CONCLUSION

Beam phase space jitter is reduced by dispersion suppression after J-ARC section. Under 1 nC operation, the effect to effective emittance is small. However jitter emittance is still enhanced after the target. In phase 3, 4 nC high-charged low emittance electron beam will be required for HER (High Energy Ring). Therefore, we have to investigate the source of the beam phase space jitter continuously to reduce the risk of emittance growth.

Enhancement factor, which is the ratio of beam position jitter after to before the target, is not significantly changed by dispersion suppression. Dependence on flux concentrator, solenoid, bridge coil, pulsed magnet, and chicane is small.

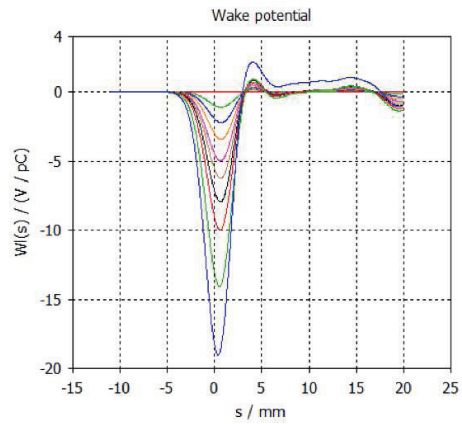

Figure 7: Transverse wake potential induced by positron generation target. Color variation shows beam position from the center of the target hole, 0.1 mm, 0.2 mm, ..., 0.9 mm.

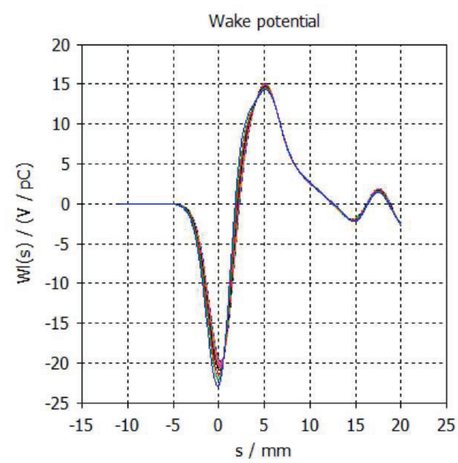

Figure 8: Longitudinal wake potential induced by positron generation target. Color variation shows beam position from the center of the target hole, 0.1 mm, 0.2 mm, ..., 0.9 mm.

Though the target hole is being suspected as a beam jitter source, simulation result suggest that the wake field effect is small as far as design beta function or gaussian beam is assumed. We will check beta function and beam profile around the positron generation target.

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