OPTICS DESIGN AND OBSERVATION FOR THE BEAM ABORT SYSTEM IN THE SuperKEKB HER

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Abstract

In the first commissioning of SuperKEKB [1], Phase 1, the new abort system was tested in the High Energy Ring (HER). There is a risk that aborted beams with low emittance and high current may destroy the window for extraction from beam pipe. One way to enlarge the size of the aborted beam at the window is to apply a quadrupole field without affecting the stored beam in the ring. In the Low Energy Ring (LER), quadrupole pulsed magnets are planed to install to enlarge the aborted beam. A sextupole magnet is installed between the abort kickers and the extraction window in the HER. Another identical sextupole magnet is also placed to cancel geometrical aberrations. This paper reports the optics design for the abort system in the HER as well as the observation of aborted beams.

INTRODUCTION

The SuperKEKB B-factory is an upgrade of KEKB, which is a double ring collider consisting of the HER (7 GeV electrons) and the LER (4 GeV positrons). The circumference is about 3 km. It aims at a very high luminosity of 8×10^{35} cm^{-2}s^{-1} with low emittance beams based on so-called "Nano beam" scheme [1]. The horizontal and vertical emittances, maximum total beam currents of the HER at SuperKEKB (KEKB) are 4.6 nm (24 nm), 12.9 pm (150 pm), and 2.6 A (1.2 A), respectively, and at the LER 3.2 nm (18 nm), 8.6 pm (150 pm), and 3.6 A (1.6 A), respectively, for the design parameters. Although the abort system is indispensable for such a machine with high beam current, there is a risk of destroying the abort window when such a low emittance beam passes through the vacuum duct to the atmosphere [2].

In order to protect the window from destruction due to the energy deposit of the aborted beam, the energy density of the beam must not concentrate at the window. The schematic design of the abort system of the HER is shown in Fig. 1. The abort system of KEKB consisted of several horizontal kickers, a vertical kicker, a Lambertson septum, and a beam dump. The abort window is located just in front of the Lambertson magnet. The new horizontal kickers [3] with a fast rising time (~150 ns) deflect the beam out of the chamber, and the vertical kicker slowly sweeps the beam train by 15mm on the window, to disperse the energy deposit of the entire bunches. The vertical sweep is effective for a horizontally flat beam. Since the emittances of SuperKEKB become one order smaller than those of KEKB, we make the horizontal beam size at the window larger by enlarging the horizontal beta function there, in addition to the vertical sweep.

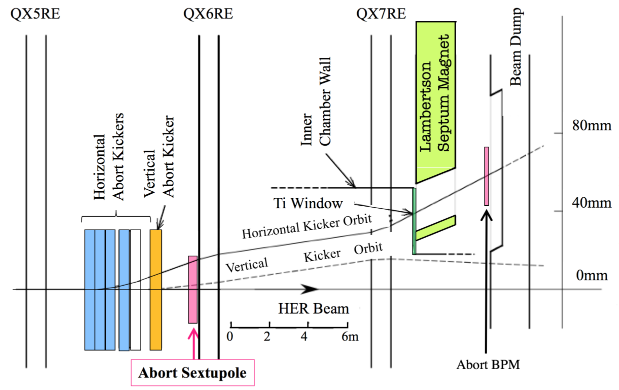

Figure 1: The schematic layout of the abort system in the HER of SuperKEKB. The horizontal axis shows the distance along the electron beam. The transverse orbits at abort system region are shown. The stored beam passes the center of the abort sextupole. On the other hand, the aborted beam passes off-center of the sextupole.

In the LER, the pulsed quadrupole will be used to enlarge the beta function at the abort window in Phase 2 operation starting in early 2018. In the HER, because the beam energy is higher than the LER, a larger number of quadrupoles would be needed. Instead of pulsed quadrupoles, we decided to install a DC sextupole between the abort kickers and the abort window, where only the aborted beam feels the quadrupole components from the sextupole. The DC magnet has an advantage on the stability than the pulsed magnet. Unfortunately it is not possible to install a similar system in the LER due to a limitation on the space. In this paper, we mainly focus on the abort optics of the HER.

OPTICS DESIGN

The abort system of SuperKEKB is located in the vicinity of the injection point. In Phase 1, the electron beam was injected with a on-energy betatron injection scheme. As an off-energy synchrotron injection scheme [4] will be prepared in Phase 3 which will start in autumn 2018, we made abort optics for both cases. The optics designs were calculated with the computer code SAD [5]. Figure 2 shows the optics in the betatron injection scheme for the aborted beam and the stored beam, respectively. The horizontal displacement of the aborted beam at the abort window from the stored beam is 40 mm. The aborted beam deflected by the horizontal kickers passes through the sextupole with a horizontal offset and extracted. The sextupole makes the horizontal beam size at the window large to be 1.1 mm from 0.1 mm, in order

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to avoid to destroy the window at the full beam current. The total kick angle of the horizontal and vertical kickers are 2.69 mrad and 1.44 mrad, respectively, and $K2 \equiv B''\ell/B\rho$ of the sextupole is 4.29 m^{-2}.

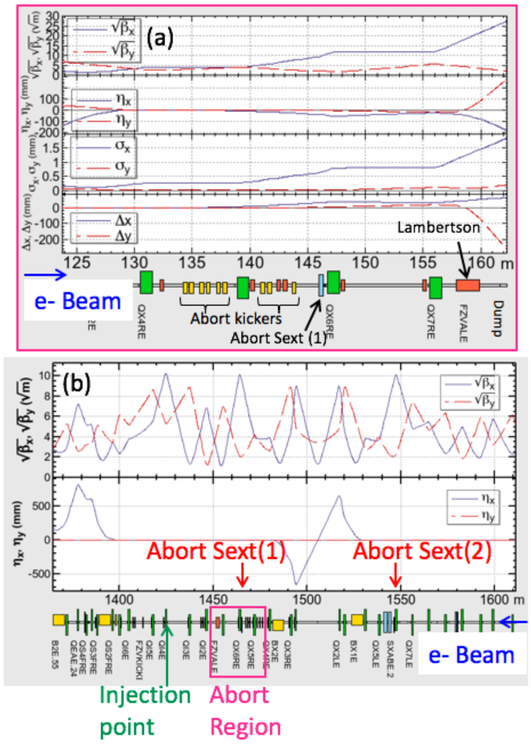

Figure 2: Optics for the betatron injection scheme. The black and red lines correspond to the horizontal and vertical plane, respectively. (a) Beta functions, dispersion functions, beam sizes, and orbits for the aborted beam in the abort region indicated by the red square in (b). The beam comes from the *left* side. (b) Beta functions, dispersion functions for the stored beam in the injection region of the HER. The beam comes from the *right* side.

Since the DC sextupole magnet degrades the dynamic aperture for the stored beam, it is necessary to add another sextupole which is connected by $-I$ or I transformation to cancel the geometric aberrations. As shown in Fig. 2-(b), the phase advance between the two sextupoles is 1.5π and π in the horizontal and vertical plane, respectively, and the beta functions at the center of the sextupoles are same for both planes. There is no dispersion at the sextupoles. Figures 3-(a) and (b) show the optics for the off-energy synchrotron injection scheme of the aborted beam and the stored beam, respectively. Since there is a horizontal dispersion in the abort section, it is adjusted to make a zero-crossing point at the center of the sextupole magnet (1) for the stored beam optics. The horizontal displacement between the aborted beam and the stored beam at the abort window is 38 mm. The horizontal beam size becomes 1.2 mm. The total kick angle of the horizontal and vertical kickers are 2.70 mrad and 1.27 mrad, respectively, and $K2$ of the sextupole is 4.07 m^{-2}.

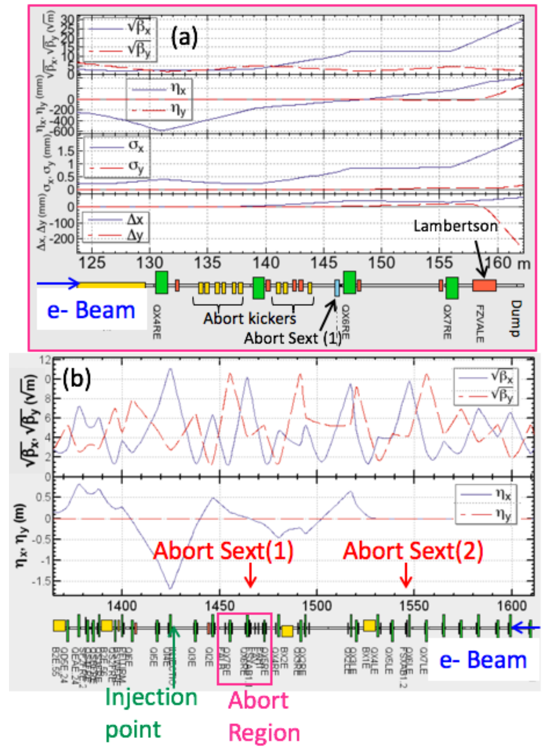

Figure 3: The optics for the synchrotron injection scheme. Notations are the same as in Fig. 2.

Dynamic Aperture

We made a simulation for the influence of the sextupole pair in the straight section and estimated the Touscheck beam life time. Figure 4 shows the dynamic apertures in the HER for the Phase 3, where the beta functions at the interaction point are the design value $\beta_{x,y}$ ={25, 0.30} mm. The beam lifetime is optimized with different sextupole setting for each case. As Touscheck beam lifetime is insensitive to the

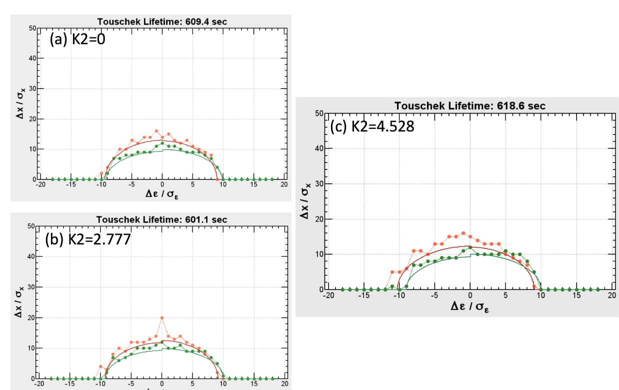

Figure 4: The dynamic apertures for the on-energy injection scheme are shown. Red dots indicates (ϕ_{x0}, ϕ_{y0})=(0,0) for the initial betatron phases and green dots for (ϕ_{x0}, ϕ_{y0})=(π/2,π/2). The $K2$ values of the abort sextupole pair are, (a) zero, (b) 2.78 m^{-2} (half of the design value) and (c) 4.53 m^{-2}(design value). The Touschek beam lifetimes are estimated by the inner-fitted lines as (a) 610 s, (b) 600 s, and (c) 620 s, respectively.

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sextupole magnetic field, $K2$, no adverse effect due to the insertion of the abort sextupoles has been seen.

Hardware Components

The kickers for the abort system are described in [3] and [6] in detail. The specification of the sextupole magnet for the abort system is more or less conventional. The maximum absolute $K2$ is 6.42 m^{-2}, and the bore radius, effective length, and B'' are 56 mm, 0.335 m, and 447 Tm^{-2}, respectively. The specification of the power supply is 600 A× 22 V.

The size of the abort window was designed so that the beam can pass through it safely even considering a 3.5σ beam size, an energy deviation of ±1%, and a coherent oscillation simultaneously. The maximum vertical coherent oscillation considered is $50\sigma_y$ which is determined by acceptance limited by the vertical collimators to protect the Belle II detector. As for the horizontal coherent oscillation, we assume $8.4\sigma_x$ as the maximum and the beam abort is planed to be triggered when the oscillation amplitude exceeds this limit value. The designed cross section of the chambers are shown in Fig. 5. With the above considerations, the aborted beam is confined within the region shown with the red rectangle in Fig. 5-(b). As shown in Fig. 2-(a), the horizontal orbit deviation of the aborted beam becomes maximum at "Abort Sext(1)" in the beam pipe. The horizontal and vertical sizes of this region are 8.4 σ_x and $51\sigma_y$ of the aborted beam plus the vertical sweep (15 mm), respectively. Note that the vertical beam size of the aborted beam is larger than that of the stored beam by the part of the vertical dispersion created by the vertical kicker. We consider the tail of the aborted bunch train. The beam abort window was designed so as to include the red rectangle region. These beam pipes must have a larger aperture than the abort window.

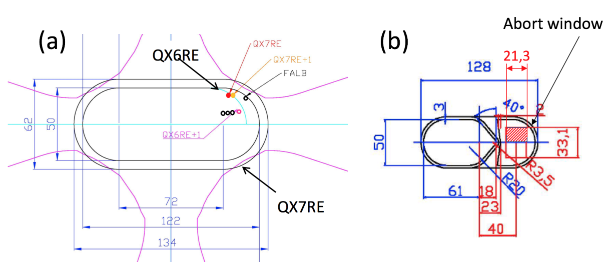

Figure 5: (a) The cross section of the chambers for the inner chamber of quadrupoles QX6RE and QX7RE which locate between the abort kickers and the Lambertson. The dots show the positions where the beam are closest to the chamber walls with the coherent oscillation. (b) The cross section of the abort window. The red rectangle shows the region where the aborted beam passes.

PERFORMANCE IN PHASE1

We commissioned SuperKEKB Phase1 without the final focus system from February to June 2016. The maximum total beam current was 870 mA in the HER. In this operation, the new HER abort system has succesfully worked as planned [7]. In front of the beam dump of the abort system, a beam position monitor (BPM) and a screen monitor are installed to observe the aborted beam. Furthermore, the beam size was measured by irradiating the beam to an aluminum phosphor with a thickness of 0.2 mm installed in front of the abort window. In this measurement, a single bunch electron beam with 0.1 nC was used. Figure 6 shows the result of the size measurement. The light from the emitter was captured by a video camera, and projected into the horizontal direction. The result was 1.18 ± 0.16 mm including the multiple scattering at the window and the thickness of the screen. It was confirmed that the abort beam size is enlarged to the designed value of 1.1 mm.

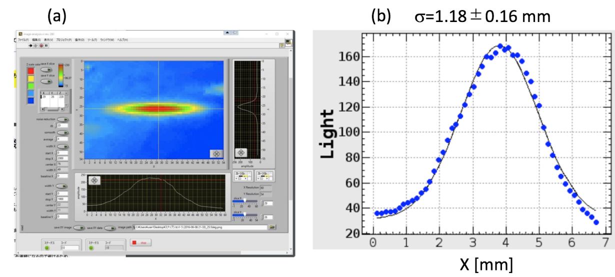

Figure 6: (a) The captured image of the aborted beam. (b) The horizontally projected beam size fitted by Gaussian.

CONCLUSION

We made optics design for the new abort system in the HER at SuperKEKB. The difference from KEKB is that the horizontal beam size is enlarged not to destroy the abort window by using a pair of sextupole magnets. The sextupoles does not change the beam life time of SuperKEKB because these magnets are connected by I or $-I$ transformation to cancel the geometrical aberration for the stored beam in the ring. We have designed the abort optics with both betatron injection and synchrotron injection scheme. We confirmed that the abort system works well as we designed in the operation of Phase 1.

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