CANCELLATION OF THE LEAK FIELD FROM LAMBERTSON SEPTUM FOR THE BEAM ABORT SYSTEM IN THE SuperKEKB

N. Iida*, M. Kikuchi, K. Kodama, T. Mimashi, T. Mori, Y. Ohnishi,
K. Oide, H. Sugimoto, and M. Tawada
KEK, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

The first commissioning of SuperKEKB, which is Phase 1, has been performed from February 2016 for five months. A Lambertson septum magnet is utilized to deliver the aborted beam, which is kicked by the horizontal abort kickers upstream, into a beam dump. The Lambertson magnet induces an unexpected large magnitude of a leak field with a skew quadrupole component for the stored beam. Two kinds of skew quadrupole magnets are installed at the both sides of the Lambertson septum to correct the skew quadrupole component. One is additional skew windings on a regular sextupole magnet, and the other an additional skew quadrupole permanent magnet. This paper reports that the leak fields are successfully canceled with these magnets which are useful for the optics correction.

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) whose circumference is about 3 km. It aims at a higher 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 HER at SuperKEKB (KEKB) are 4.6 nm (24 nm), 12.9 pm (150 pm), and 2.6 A (1.2 A), respectively, and those of the LER are 3.2 nm (18 nm), 8.64 pm (150 pm), and 3.6 A (1.6 A), respectively. The abort system is indispensable for such a machine with high beam current [2] [3]. The schematic design of the abort system of the HER, for example, is shown in Fig. 1. This system consists of horizontal kickers, a vertical kicker, DC sextuple for the the HER, a Lambertson septum, and a beam dump. The “abort window”, for beam extraction to atmosphere is placed just in front of the Lambertson magnet. The horizontal kickers [4] with fast rising time (~150 ns) kick the beam out of the chamber, and the slow vertical kicker sweeps the beam train by 15mm on the window, to disperse the energy deposit of the entire bunches. The kicked beam out of the beam pipe is bent vertically by the Lambertson septum to be led into the beam dump. The detail is mentioned in Ref. [3].

The first trial run of SuperKEKB was done without collision from February to June 2016. The important fundamental tests were successfully done, such as the confirmations of no serious failure on hardware, establishing the calibrations, the optics measurement and correction methods, the vacuum pipe scrubbing, the background study for the coming

* naoko.iida@kek.jp

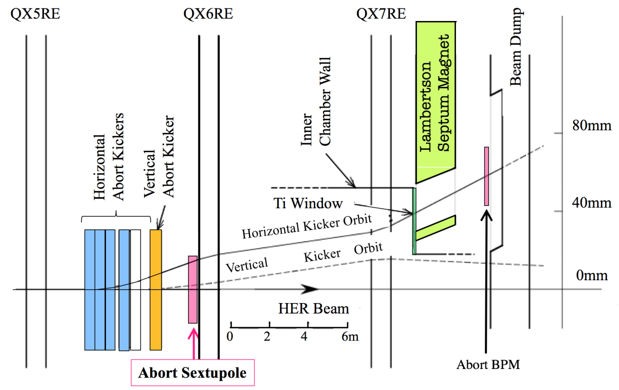

Figure 1: The schematic layout of the abort system in the HER of SuperKEKB. The horizontal axis shows the distance along the direction of the electron beam. The transverse orbits of the aborted beam are shown. The stored beam passes through the center of the abort sextupole.

Belle II detector, and the low emittance adjustment [1] [5]. The leak field from the Lambertson septum influenced the dispersion function and the X-Y coupling. In this paper, we describe that the cancellations of the leak field which are important for achieving the low vertical emittance required by the luminosity goal.

X-Y COUPLING CORRECTION

In SuperKEKB, optics measurement and correction are performed in the three steps [6], beta functions, horizontal-to-vertical (X-Y) coupling, and dispersion functions. The beta function is measured by the orbit responses induced by six different dipole correctors for the horizontal and vertical plane [7]. The X-Y coupling is measured by the leaked orbit to the vertical plane from six different horizontal dipole correctors. The physical dispersion function is measured by the orbit displacement due to an RF frequency shift. Each correction gradually converges to the model with a few iterations. Here the X-Y coupling and the vertical dispersion are corrected by independent knobs. The arc lattice of the SuperKEKB rings consist of 2.5π unit cells that include non-interleaved sextupole pairs. About 50 pairs of sextupoles are placed in the whole ring. Each sextupole pair is connected with a $-I'$ transformation. The sextupoles have a skew-quadrupole-like auxiliary winding to be used for the corrector knobs. The opposite sign of the skew quadrupole field between the paired sextupoles can correct the vertical dispersions without disturbing the X-Y coupling out side of the pair, and the same sign vice versa. Because of the non-interleaved sextupole scheme, the corrections of vertical physical dispersions and X-Y coupling can be solved nearly independently to each other.

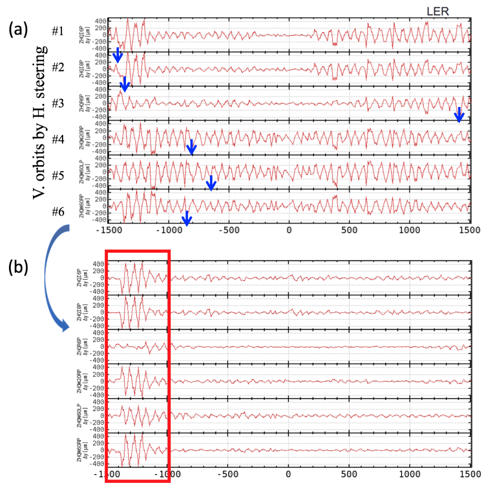

Figure 2: Measurements of X-Y couplings of the LER (a) before and (b) after the correction. The horizontal axis shows the orbit distance from the interaction point in unit of m. The vertical axis shows the vertical closed orbit distortion (COD) in unit of μm. The six columns represent the CODs induced by the six independent horizontal dipole kicks indicated by blue arrows.

The plots before and after X-Y coupling correction are shown in Fig. 2. The correction effectively works well, but uncorrectable X-Y coupling remains in the red square of Fig. 2-(b), where the Lambertson septum for the abort system is located. As long as this coupling remains, there is a limitation on reducing the vertical emittance. The influence on the dispersion by the leak field is especially large in the LER.

The kick angle, length, and magnetic field of the Lambertson septum are 79 mrad, 2 m, and 0.92 T for the HER, 115.5 mrad, 1.5 m, and 1.0 T for the LER, respectively. The leak of magnetic field affects the stored beam as shown in Fig. 3, and mainly leaks at its both ends. The leaked fringe field, which is emphasized in the figure, applies a vertical dipole kick as well as a skew quadrupole component on the stored beam. In order to shield this leak field, an iron plate is attached to each end of the Lambertson, but it is not sufficient.

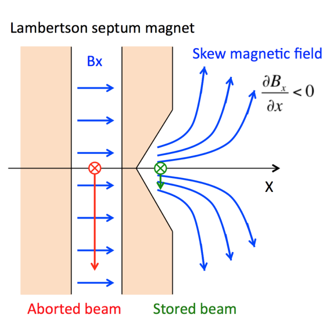

Figure 3: A conceptual drawing of the magnetic fields around the beams, integrated along beam axis.

To cancel the leak field, two additional skew quadrupole magnets were installed on the both sides of the Lambertson septum. As shown in Fig. 4, there is a regular sextupole magnet in the ring with a skew quadrupole winding on the downstream of Lambertson. Since the focusing sextupole in the near arc region of the Lambertson magnet has not been used to correct the X-Y coupling, the first way is to involve the corrector winding. By using this winding for the correction, the X-Y coupling has been improved as shown in Fig. 5-(a) to (b).

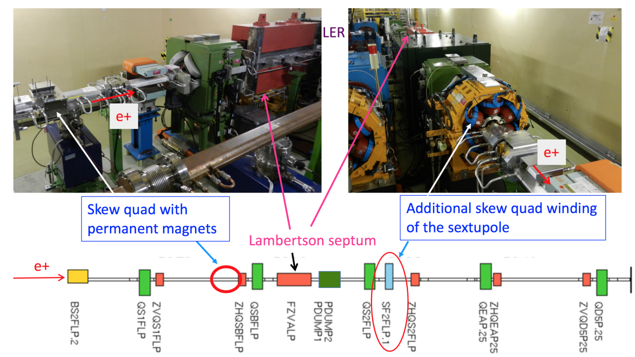

Figure 4: The lattice around the Lambertson magnet are shown in the bottom of the figure. The picture of the left side is the upstream of the magnet. The corrector winding is indicated by blue color, on the sextupole in the right picture.

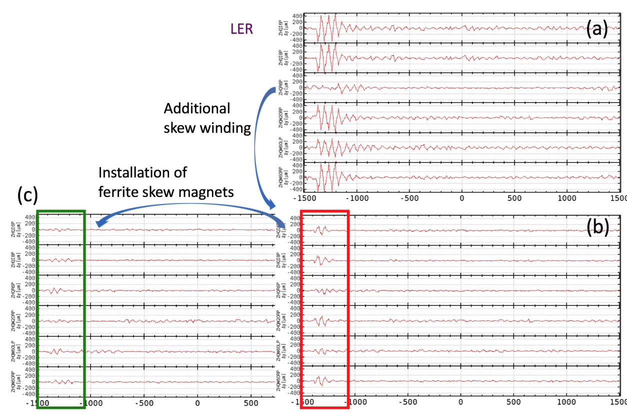

Figure 5: X-Y coupling measurements (a) before no correctors. (b) after installation of the additional skew winding. (c) after installation of the skew permanent magnets.

SKEW QUADRUPLE WITH PERMANENT MAGNET

The second method is to install a skew quadrupole permanent magnets upstream of the Lambertson magnet. We estimate that an additional skew quadrupole component with strength of SK1$\equiv B'\ell/B\rho = 8\times10^{-3}$ m^{-1} is necessary upstream of the Lambertson to correct the leak field in Fig. 5-(b). In order to make this field, ferrite blocks were used with a dimensions $L\times W\times D$ = 150 mm$\times$100 mm$\times$25.4 mm. The magnetic fields at the center of each block were measured as shown in the Table 1.

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Table 1: Measured Magnetic Fields B_0 [mT]

	Front	Back
Block No.1	50	43
Block No.2	55	46
Block No.3	49	46
Block No.4	53	49

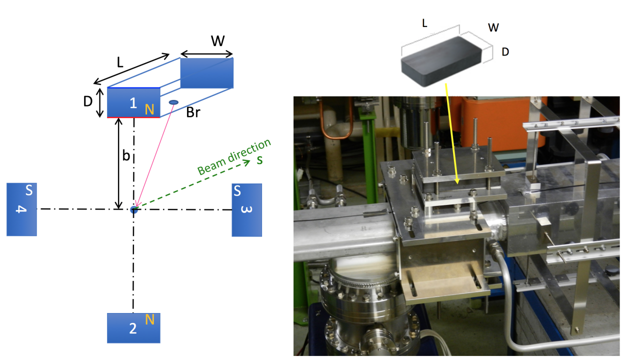

Figure 6: The setup of the ferrite blocks to produce the skew quadupole component.

A stronger surface was placed on the side closer to the beam. To make a skew quadrupole magnet with the blocks, we calculated the field with the geoemtry shown in Fig. 6, then obtained the following expression for the integrated skew quadrupole component:

$$B'L = \frac{8B_r LW}{\pi}\left(\frac{1}{4b^2 + W^2} - \frac{1}{4(b+D)^2 + W^2}\right), \quad (1)$$

where B_r is the residual magnetic flux density and b is the inner distance between the block and the stored beam. In the case with the central magnetic field of 0.055 T, the required B_r is about 0.3 T.

The distance from the beam to the inner surface of the ferrite block was 85.5 mm. At the first trial of the ferrite skew quadrupole with this distance, the field strength was slightly stronger than needed for the X-Y coupling correction. It is considered that this discrepancy comes from the variety of strengths between the blocks. Then a weaker skew quadrupole, SK1=6×10^{-3} was required. After changing the distance b from 85.5 mm to 97.5 mm, the remaining X-Y coupling almost disappeared as shown in Fig. 5-(c).

Figure 7 shows the measured vertical dispersions before and after installing the ferrite blocks. A sharp peak in the vertical dispersion also vanished. As a result of this correction, the r.m.s. residual orbit was reduced from 6 mm to 4 mm and the strong correctors in other locations disappeared by using the permanent skew quadrupole.

We installed a ferrite block in the HER as well as in the LER. The skew quadrupole of strength of SK1 = 3×10^{-3} was needed downstream of the HER Lambertson. When the central magnetic field is 0.03 T, the B_r value is about 0.16 T for the same size of ferrite. The field was too strong in this case that the distance from the beam to the inner

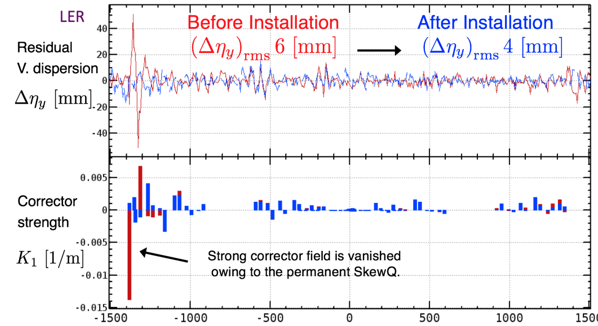

Figure 7: The residual vertical dispersion and the corrector strength used in the correction. Red and blue lines are before and after the installation of the permanent skew quadrupole, respectively.

surface of the ferrite block was 80 mm. Then an additional SK1 = -1×10^{-3} was necessary. Instead we employed a coin-type permanent magnet with 15 mm in radius, 8 mm in thickness, and the central magnetic field 0.07 T. Four sets of such skew quadrupoles were installed at 65 mm between the inner surface of the ferrite and the beam center.

Figure 8 shows the results of the correction of the vertical dispersion and the vertical emittance in the LER [6]. The vertical dispersions are clearly smaller by iteration of the correction. After installation of the two types of skew quadrupoles, both the vertical emittance and r.m.s. of the vertical dispersion are dramatically reduced. The vertical emittance achieved less than 10 pm which is the target value of the SuperKEKB in Phase 1.

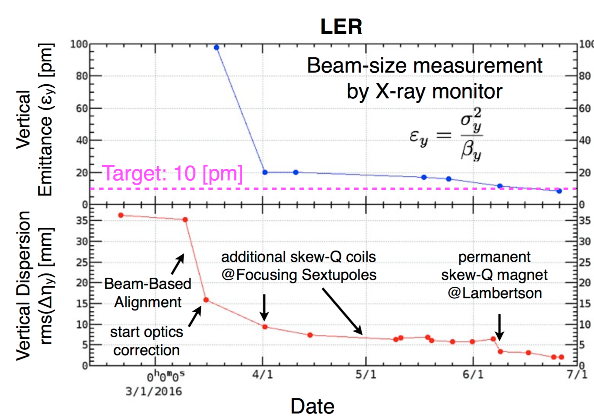

Figure 8: Histories of the measured vertical emittance and the vertical physical dispersion in the LER.

CONCLUSION

In SuperKEKB, the vertical dispersion generated by the leak field from the Lambertson septum is corrected by using the skew quadrupole correctors. After adding the skew quadrupole winding to the sextupole magnet and the skew quadrupole made of permanent magnets on the both sides of the Lambertson magnet, the vertical dispersion around Lambertson has almost disappeared. As a result, the vertical emittance was measured lower than the target value.

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