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OPTICS CORRECTIONS INCLUDING IP LOCAL COUPLING AT SuperKEKB*

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Abstract

SuperKEKB is an asymmetric energy electron-positron collider designed by using a novel collision scheme. The beam collision test was performed during the phase-2 commissioning. In the phase-2 commissioning, global optics corrections worked fine except for local coupling at the interaction point(IP). IP local coupling was adjusted by IP tuning knobs to maximize luminosity. After IP local coupling adjustment, the specific luminosity improvement by squeezing the vertical beta function at IP down to half of the bunch length was confirmed.

INTRODUCTION

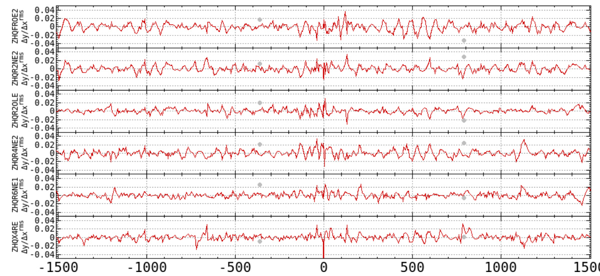
The SuperKEKB accelerator [1] is an asymmetric energy electron-positron collider which is designed to achieve a luminosity of $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ by using the "nano-beam" collision scheme. Its main rings are constructed by 7 GeV electron high energy ring (HER) and 4 GeV positron log energy ring (LER). The SuperKEKB accelerator commissioning is divided into 3 phases. At this moment, the second phase so called "phase-2 commissioning" has been completed and we are preparing the phase-3 commissioning.

The phase-1 commissioning [2] without the final focus system was performed from February 1, 2016 to June 28, 2016 for establishing the low emittance beam operation. After the phase-1 commissioning both the final focus system and the Belle II detector were installed. The phase-2 commissioning [3] was performed from March 19, 2018 to July 17, 2018 to verify "nano-beam" collision.

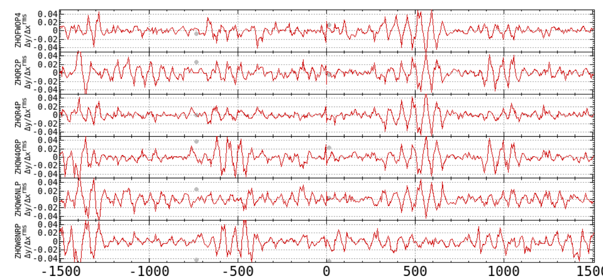
In the following sections, the global optics correction performed as a part of beam commissioning and the IP local coupling issue are reported.

GLOBAL OPTICS CORRECTION

Both optical function measurement and correction algorithm for the phase-2 beam operation are same as the phase-1 commissioning [4]. The optical function measurement of the SuperKEKB standard operation is based on the closed orbit response measurement by using the multi-turn beam position monitors(BPMs). In the optics correction, the correction parameter is calculated from both the linear model response and the measured optical function error by using the singular value decomposition (SVD). The global optics correction sequence for the beam operation contains XY-coupling correction, physical dispersion correction and beta correction.

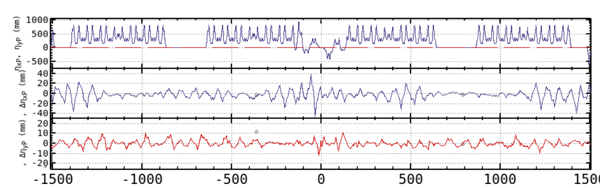


(a) HER

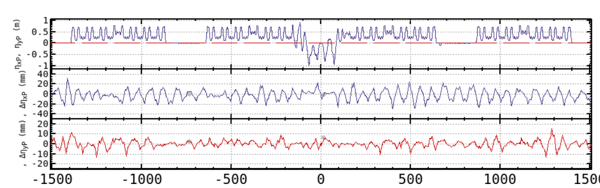


(b) LER

Figure 1: XY-Coupling measurement. Horizontal axis shows the distance from the IP in m units. Each graph columns show the discrepancy between model prediction and measurement of vertical leakage orbit of single horizontal steering kick shown in column label.



(a) HER



(b) LER

Figure 2: Physical dispersion measurement. From the top of the graph columns, graph columns correspond with model dispersion, horizontal dispersion error and vertical dispersion error, respectively.

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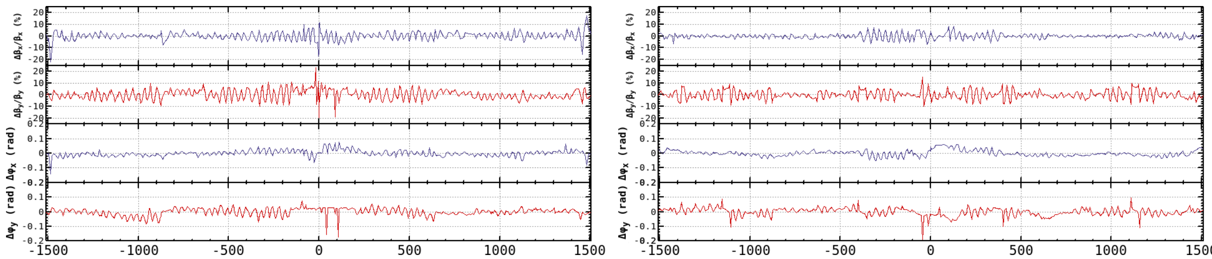

(a) HER (b) LER

Figure 3: Beta function measurement. From the top of the graph columns, graph columns correspond with relative horizontal beta function error, horizontal betatron phase error, relative vertical beta function error and vertical betatron phase error, respectively.

The global optics corrections work fine enough for the phase-2 optics. Figures 1, 2 and 3 show the normalized vertical orbit leakage of the horizontal single steering kick response (XY-coupling error), the physical dispersion error and the relative beta-function error, respectively. These optics errors were measured on $\beta_y^* = 3$ mm collision optics after global correction at the end of phase-2 commissioning. The residual errors are summarized in Table 1, where $\triangle y^{rms}$ and $\triangle x^{rms}$ are rms error amplitude of the vertical leakage orbit and rms amplitude of the horizontal single steering kick perturbation, respectively. These residual errors are almost same as the phase-1 achievements shown in the previous eeFACT paper [5] except for the LER XY-coupling error residual. The LER XY-coupling error shown in Fig. 1b is not localized around the IP which is shown at the center of the figure. The vertical alignment error due to the SuperKEKB tunnel subsidence and the permanent magnet device installed to suppress the electron cloud effect are suspected as the XY-coupling error source. In order to achieve ultra low emittance, further XY-coupling correction study is required in the phase-3 commissioning.

Table 1: Results of Optics Corrections; XY-Coupling, Physical Dispersion, and Beta Function

Item	LER	HER	Unit
XY-coupling: $\triangle y^{rms}/\triangle x^{rms}$	1.4	0.8	%
Hor. dispersion: $\triangle\eta_{x\,Phys.}^{rms}$	10.6	9.8	mm
Ver. dispersion: $\triangle\eta_{y\,Phys.}^{rms}$	3.7	3.1	mm
Hor. β function: $(\triangle\beta_x/\beta_x)^{rms}$	2.2	3.6	%
Ver. β function: $(\triangle\beta_y/\beta_y)^{rms}$	3.8	4.5	%
Hor. tune: $\triangle\nu_x$	3.6	-0.8	10^{-4}
Ver. tune: $\triangle\nu_y$	-0.05	-4.8	10^{-4}

IP LOCAL COUPLING

At β_y^* squeezing from 6 mm to 4 mm, the specific luminosity improvement corresponding with β_y^* squeezing was not observed. The vertical beam size measurement by using X-ray beam size monitor at the end of the arc section and global XY-coupling & dispersion measurement results suggest that the vertical emittance of the single beam operation is not degraded by β_y^* squeezing.

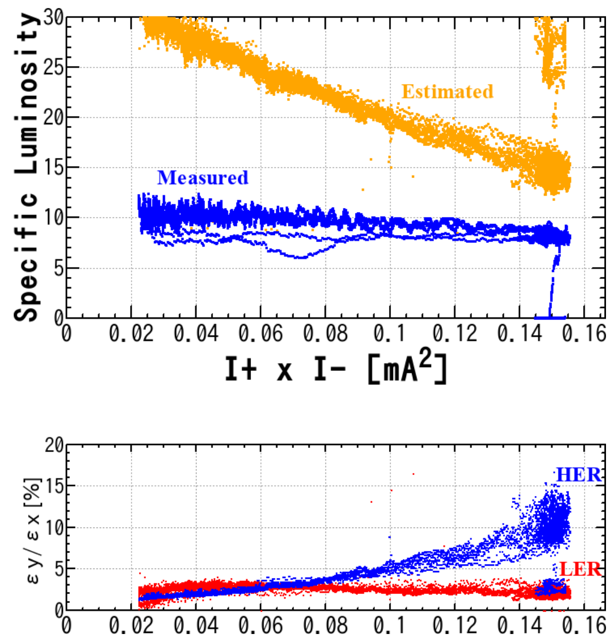

Figure 4: Specific luminosity before IP local coupling adjustment. Horizontal axis show a bunch current product. Vertical axes show the specific luminosity for upper graph and the normalized vertical emittance(square of vertical beam size) measured by X-ray beam size monitors, respectively. Blue and yellow points in the upper graph correspond with the measured specific luminosity and the specific luminosity estimated from the beam size, respectively. Red and blue points in the lower graph correspond with the LER beam and the HER beam, respectively.

Figure 4 shows the bunch current product dependency of the specific luminosity measured on such $\beta_y^* = 4$ mm collision operation with decaying beam current. In Fig. 4, the LER vertical beam size is almost kept against bunch current decay, however, the HER vertical beam size shrinks by a half corresponding with bunch current product decaying from 0.15 mA^2 to 0.03 mA^2. On the other hand, the bunch current product dependency of the measured specific

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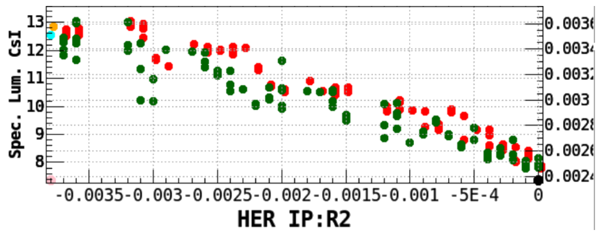

Figure 5: HER R2* parameter scan result. Horizontal axis shows R2 parameter at the IP in m units. Vertical axis shows the measured luminosity.

luminosity is small compared with the prediction from the analytic formula. Furthermore, the vertical beam size at the IP estimated from the beam-beam scan measurement at low bunch current operation by scanning vertical collision orbit offset is about 1.25 μm under the assumption that the IP vertical beam sizes of the colliding beams are equal to each other, however, the typical vertical beam sizes measured by using X-ray beam size monitor at the decayed low current beam condition are 0.5 μm for HER and 0.4 μm for LER, respectively. These results suggest the geometrical beam mismatch at the IP.

In order to find the source of such geometrical beam mismatch, the vertical beam waist scan, the IP coupling parameter scans (R1*, R2*, R3*, R4*) and the IP vertical dispersion scans($\eta_y^*, \eta_{y'}^*$) were performed, where R1, R2, R3 and R4 parameters are described by using the x-y-coupling parameter definition of the accelerator code SAD [6]. From such IP parameter scans, a large HER R2* error shown in Fig. 5 is found. At this moment, R2* parameter scan range is limited within almost 3.8 mm by the maximum excitation current of skew quadrupole corrector winding on chromaticity corrector sextupole magnet pair, however, this scan range is not enough to find the luminosity peak. In order to search correct R2* parameter, the old IP tuning knob based on the vertical local bump around sextupole magnet pair, which is used in the KEKB B-factory tuning [7], is temporarily reintroduced to extend R2* parameter scan range. The total amount of R2* adjustments at the luminosity peak of R2* scans is about 6 mm.

Finally, this big R2* error is adjusted by using the skew quadrupole corrector of the vertical final focus quadrupole magnets(QC1 magnets). Figure 6 shows the specific luminosity trend after these IP local coupling adjustments. In Fig. 6, the vertical beam size blowup is reduced and the IP vertical beam size estimated by the beam-beam scan measurement becomes almost half and the measured specific luminosity approaches to the predicted performance by inverse square root of β_y^*.

SUMMARY

The global optics correction works fine enough for the phase-2 optics, however, IP local coupling must be suppressed for obtaining good luminosity performance. The global XY-coupling & dispersion measurement by using

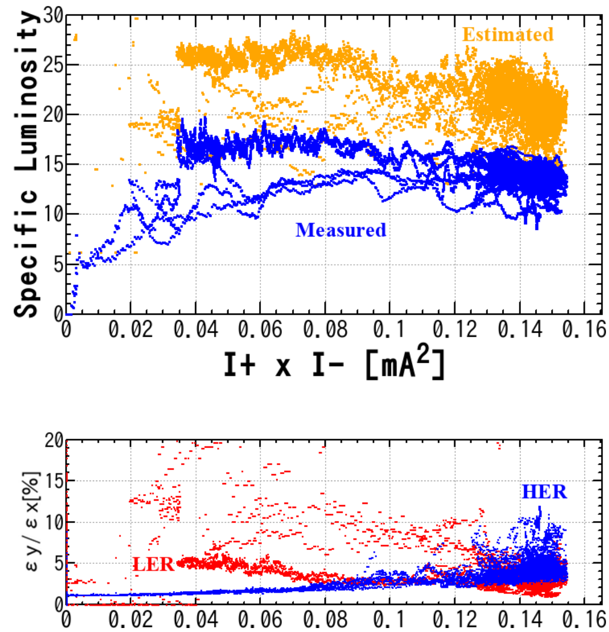

Figure 6: Specific luminosity after IP local coupling adjustment. Notations are same as Fig. 4.

BPMs installed around quadrupole magnets can not detect IP local coupling. In order to suppress IP local coupling, we have to adjust IP coupling/dispersion tuning knobs to maximize the measured specific luminosity. After IP local coupling adjustment, we confirm the specific luminosity improvement by squeezing β_y^* down to 3 mm which is about half of the bunch length.

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