ESTIMATION OF ORBIT AND OPTICS DISTORTION OF SUPERKEKB BY TUNNEL DEFORMATION

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Abstract

The SuperKEKB uses the tunnel which is same as the KEKB B-factory. The uneven settlement of the KEKB tunnel has been about 25mm at maximum for 10 years during the KEKB operation. In order to keep a high luminosity, a vertical emittance growth should be kept enough small by applying orbit and optics corrections. We has estimated the vertical emittance growth due to the tunnel subsidence and studied the feasibility of the correction scheme.

INTRODUCTION

The SuperKEKB[1, 2, 3] is an asymmetric-energy double-ring collider. It is the upgrade plan to achieve 40 times higher luminosity than that of the KEKB B-factory. The main rings of the SuperKEKB are under construction now in the KEKB tunnel which was used for the previous KEKB B-Factory.

The uneven settlement of the KEKB tunnel has been observed during the KEKB operation since 1998. The temporal and regional behavior of vertical displacements of the magnets is shown in Fig.1. The interaction point(IP) is located at $s = 0$ which is the reference of the level in Fig.1. The whole components of KEKB B-factory were almost aligned in a plane surface at the beginning of the operation. The maximum depth of the measured uneven settlement was almost reached 25mm at the end of the KEKB operation June 30, 2010. The average rate of the maximum tunnel subsidence is about 2mm per year. The subsidence of the KEKB tunnel has still continued.

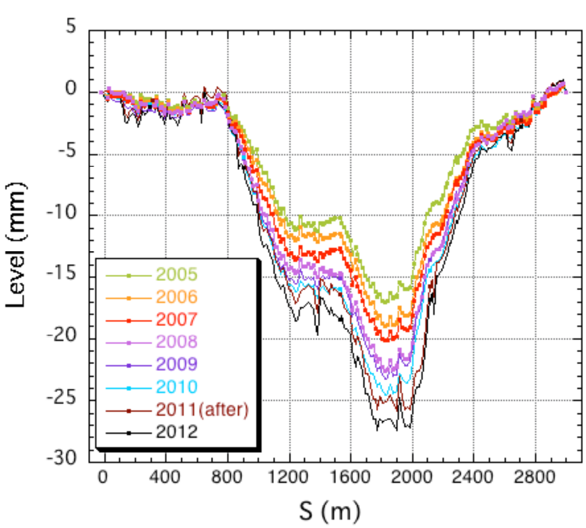

Figure 1: The level trend of the main ring. The vertical displacement of the beamline levels along the positron low energy ring from IP to IP.

In order to achieve the design luminosity, the beta-function at the IP is 20 times smaller than that of the KEKB. Consequently, the SuperKEKB optics becomes more sensitive to a machine error than the KEKB optics. In order to keep such high luminosity, both the closed orbit displacement and the optics function distortion caused by the tunnel subsidence have to be corrected. The adjustable range of the corrector elements should be wide enough to correct the machine errors due to the tunnel subsidence during the SuperKEKB operation.

In the following sections, the study of the machine error caused by the KEKB tunnel subsidence is reported.

RING OPTICS WITH TUNNEL SUBSIDENCE

In the simulation, we introduce the misalignment due to the tunnel subsidence into the optics model by using our accelerator modeling code, SAD[4]. In order to simplify the simulation model, we neglect both the tunnel displacement in the horizontal plane and the tilt of the beamline elements due to the tunnel subsidence. In this misalignment modeling, the IP level is fixed and the vertical misalignment of beamline elements are given by interpolating the measured tunnel level data by using a spline function with the scaling factor adjusting the maximum subsidence. The detector solenoid, the compensation solenoid and the final focusing superconducting quadrupole doublets in the $\pm$4m region around the IP are fixed to be the design, because those components are assembled into the same cryostat. In order to adjust a closed orbit, there are a horizontal steering magnet for each QF-type quadrupole magnet and a vertical steering magnet for each QD-type quadrupole magnet. The beam position monitor(BPM) is attached to every quadrupole magnet except for skew quadrupole magnets. In this simulation, the closed orbit is corrected toward the electric center of the BPMs in the transverse plane.

The vertical emittance, the vertical orbit error and the vertical dispersion error in the SuperKEKB high energy ring(HER) due to the tunnel subsidence are shown in Fig.2. The simulation result for the low energy ring(LER) is not described in this paper, however, its behavior is similar to the HER. In the case that the maximum subsidence exceeds 200μm without the orbit correction, the vertical emittance becomes larger than 5pm which is an allowable value to

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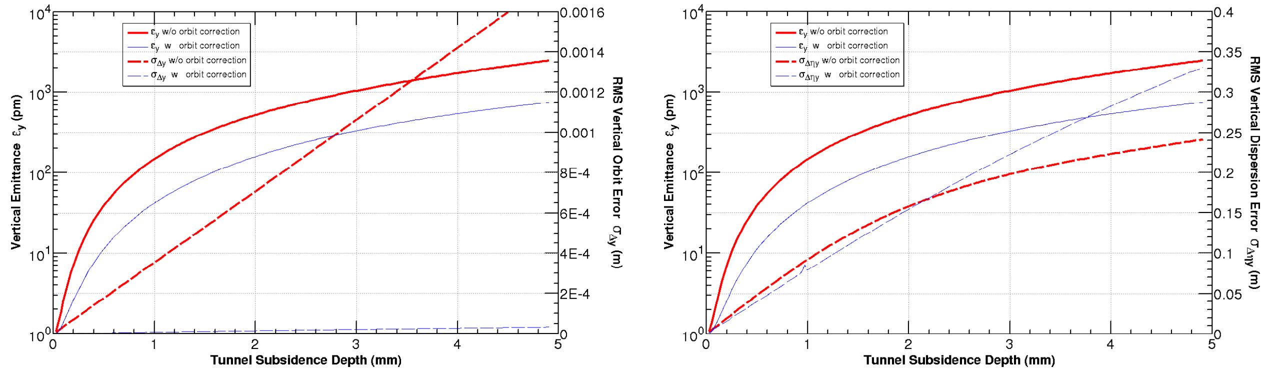
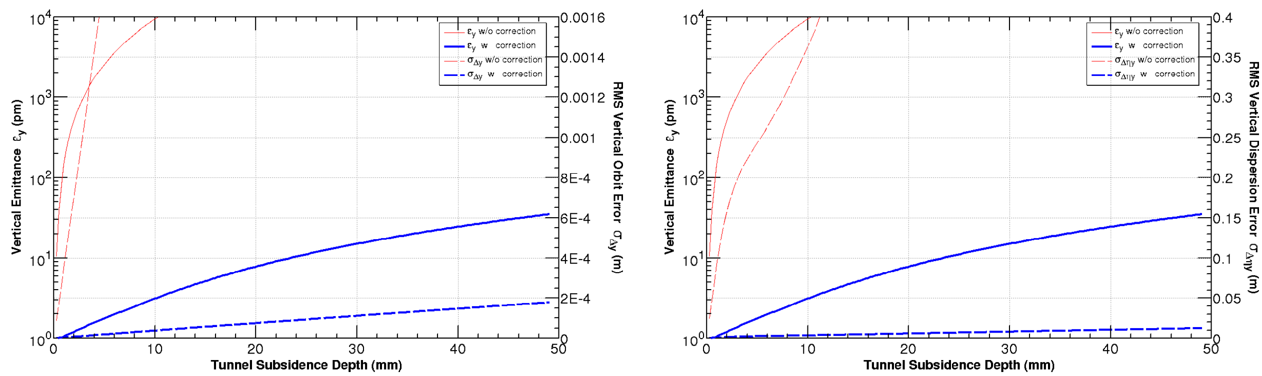


(a) Emittance & Orbit Error (b) Emittance & Dispersion Error

Figure 2: Emittance, orbit error and dispersion error in the vertical plane with or without orbit correction. The solid lines show the vertical emittance. without the orbit correction(red) and with the orbit correction(blue). The dashed lines indicate the vertical orbit error(a) and the vertical dispersion error(b), respectively. The red color shows without and the blue color shows with the orbit correction for the vertical orbit and dispersion error.



(a) Emittance & Orbit Error (b) Emittance & Dispersion Error

Figure 3: Emittance, orbit error and dispersion error in the vertical plane with or without optics correction. The meaning of the axes is similar to Fig.2.

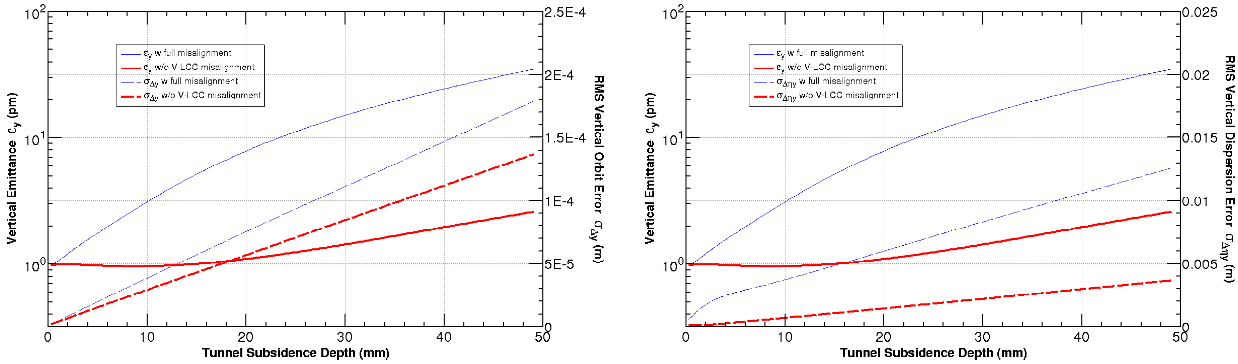
achieve the design luminosity. The vertical orbit error is improved by the orbit correction, however, the improvement of the vertical emittance is not enough for the design luminosity. The degradation of the vertical dispersion is observed in the region that the tunnel subsidence exceeds 2.2mm and this vertical dispersion is too large to achieve the target vertical emittance. This degradation is explained by a side-effect of the vertical orbit correction, because the dispersion function is not considered by our orbit correction which is only adjusted the closed orbit toward the electric center of the misaligned BPMs. Therefore, the vertical dispersion correction, which implies the coupling correction, is required to cure the vertical emittance.

TUNNEL SUBSIDENCE WITH COUPLING & DISPERSION CORRECTION

The SuperKEKB interaction region(IR) contains skew quadrupoles to adjust the coupling parameters of the IP. For global coupling and vertical dispersion correction, a skew quadrupole corrector is prepared by a back-leg winding coil in a sextupole magnet around the whole ring. In order to confirm that the coupling and dispersion correction cure the emittance growth shown in Fig.2, coupling and vertical dispersion corrections by using these skew quadrupole fields are performed in our simulation model. The optics parameters for calculating the correction parameters are given directly by that of the model optics with the tunnel subsidence, because the full-scale simulation of the measurement process of the optics parameter requires many computation time. This measurement assumption gives more information than the real measurement, however, it is reasonable enough to check correction coverage.

Figure 3 shows the improvement of the emittance growth by applying the optics correction. The vertical emittance will become larger than 5pm in 6.5 years by assuming 2mm/year average subsidence observed in the latter half of the KEKB operation. By the optics correction, the vertical emittance growth has been reduced less than one-thousandth. But it is not enough to achieve the design luminosity for the SuperKEKB.

We find out that the emittance growth with the op-



(a) Emittance & Orbit Error

(b) Emittance & Dispersion Error

Figure 4: Emittance, orbit error and dispersion error in the vertical plane for two subsidence models. The blue narrow lines and the red wide lines correspond with the reference subsidence model and the modified model excluding misalignment related V-LCC, respectively. The meaning of the axes is similar to Fig.2.

tics correction shown in Fig.3 is improved by excluding the misalignment of both the vertical local chromaticity corrector(V-LCC) and the inner matching section between the IP and the V-LCC. Figure 4 shows a comparison between the reference subsidence model and the modified subsidence model. In addition, figure 5 shows same comparison from the standpoint of correction parameters. In Fig.4-5, these two model are indicated as "with full misalignment" and "w/o V-LCC misalignment", respectively. The emittance growth of the modified subsidence model is kept within 5pm tolerance in 25 years(subsidence of 50mm). The difference of the vertical emittance between two models can be explained by the fact that the vertical dispersion error of the reference model is 3 times larger compared with one of the modified model. In addition, it is pointed out that the subsidence dependence of the vertical dispersion error in the reference model changes around 3mm depth. The behavior of the IR skew quadrupole strength in the reference model looks like different compared with the modified model and its behavior corresponds with the behavior of the vertical dispersion error. This implies that our simple coupling correction algorithm gives the wrong value of the IR skew quadrupole corrector and it degrades the dispersion function.

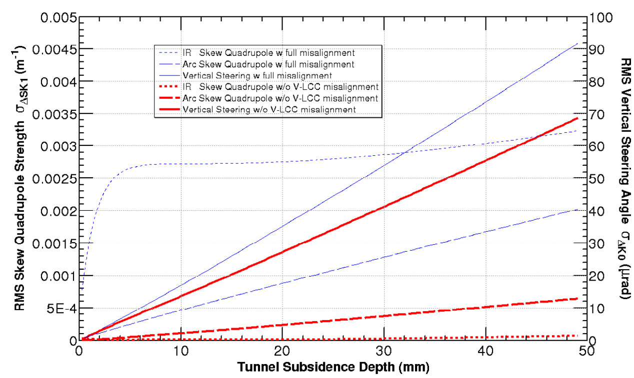


Figure 5: The correction parameter trend of two subsidence model. The horizontal and vertical axis correspond with the subsidence depth and the corrector strength, respectively. The red wide lines and the blue narrow lines correspond with the modified subsidence model and the reference subsidence model, respectively. The solid lines show the rms angle of the vertical steering magnets. The dashed and dotted lines show the rms strength of the arc skew quadrupole magnets and the IR skew quadrupole magnets, respectively.

SUMMARY

The vertical emittance due to the uneven settlement of the KEKB tunnel can be controlled within the design coupling tolerance in the case that the subsidence of the V-LCC related region is negligible small. It is known that the V-LCC is most sensitive region against the vertical misalignment. In order to suppress the emittance growth due to the V-LCC related region, the correction algorithm has to be improved. As another possibility, it can be solved by performing a particular alignment of the V-LCC related region or by selecting the skew quadrupoles to minimize the vertical beam size observed by a beam size monitor.

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