PRE ORBIT CORRECTION BASED ON TUNNEL LEVEL MEASUREMENT IN SUPERKEKB

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Abstract

The SuperKEKB accelerator tunnel has about 30mm displacement in the vertical direction. From the result of optics correction simulations with the tunnel displacement, it was decided that the beamline components align against the smoothed line of the measured tunnel level in order to save the alignment cost and time. In order to compensate the large tunnel displacement, a pre orbit and optics correction based on the tunnel level measurement is applied at the beginning of the phase-1 commissioning, and the beam circulation is achieved with a small number of magnet adjustments. We report the result of the pre correction.

INTRODUCTION

The SuperKEKB accelerator [1] is an asymmetric-energy double-ring collider constructed as a upgrade of the previous KEKB B-factory accelerator. In order to achieve 40 times higher luminosity than that of the KEKB B-factory by using the “nano-beam” collision scheme [2], the beamline around the interaction region is fully reconstructed and both the main bending magnets of the positron low energy ring(LER) and the LER beam pipes are replaced by the longer bending magnets and the beam pipes with antechambers, respectively. On the other hand, the accelerator tunnel and a lot of beamline components are reused.

The reused accelerator tunnel is sagged during the KEKB B-factory operation and the SuperKEKB construction shown in Fig. 1. The tunnel vertical levels shown in Fig. 1 are measured by using the tunnel level markers for the ring alignment, where “zero” level is defined by the reference level marker near the interaction point. At the previous KEKB accelerator construction, all level markers were calibrated to “zero” level. The maximum vertical displacement is almost reached to 35mm at the last level measurement before the phase-1 commissioning. In order to realize the low vertical emittance required for the “nano-beam” collision scheme, the vertical alignment of the beamline magnets are very important, however, the full realignment of the ring is difficult due to both cost and time limitations.

By studying the tunnel condition to achieve the low vertical emittance with the orbit and coupling-dispersion correction [3], we limit the realignment regions into the short wavelength tunnel distortion which could not be recovered by the optics and coupling-dispersion correction.

The task load for the magnet alignment is reduced by this alignment policy,but we have to correct the orbit and optics distortion due to the long wavelength vertical tunnel

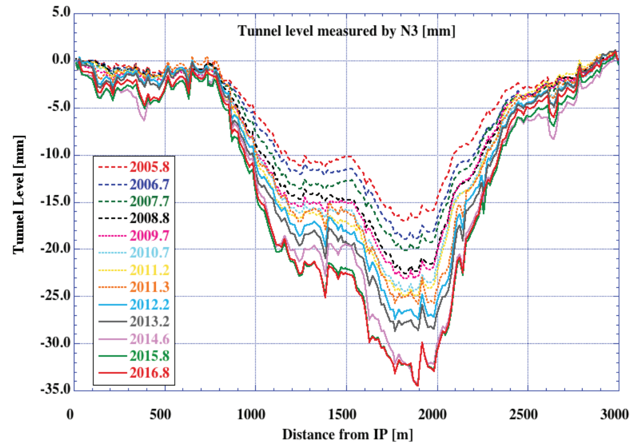

Figure 1: The tunnel level trend from the middle point of the KEKB B-factory accelerator operation to the SuperKEKB phase-1 commissioning. The vertical displacement of the beamline levels along the LER from the interaction point (IP) to the IP.

displacement which contains 35mm peak-peak tunnel subsidence exceeding the local alignment tolerance target 100μm. The correction parameters for this long wavelength tunnel alignment curve could be calculated by using the SAD [4] model lattice including the magnet level measurement result.

At the SuperKEKB phase-1 commissioning, we tried to apply pre orbit and optics (coupling-dispersion) corrections by using the optics model calculation. In the following section, we report our pre correction methods and their result.

RESIDUAL MAGNET ALIGNMENT ERROR AT THE FIRST BEAM

The magnet alignment error at the timing of the first beam circulation is classified into three kind of errors.

The first error is the reference curve of the level alignment based on the tunnel level distortion. The amplitude of this long wavelength distortion exceeds 30mm peak-to-peak. This error is possible to correct by adjusting the corrector magnet parameters, but it is big enough to prevent the closed-orbit finding at the first beam circulation. And its coupling error would be a broker issue for the first beam circulation.

The second error is the residual alignment error within the alignment tolerance. The target value of the local alignment tolerance 100μm is small enough to circulate the first beam by the phase-1 beam optics without the interaction region.

The last error is the tunnel level distortion by a secular change of the accelerator tunnel. The accurate value of the level distortion between the last precise magnet alignment

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and the first beam commissioning is unknown, because we do not have the real-time level measurement system for the whole accelerator tunnel. Considering both the tunnel subsidence trend from the year-by-year tunnel level measurement and the real-time level measurement trial in the partial tunnel section between the ground building construction [5], a secular change of the tunnel level after the precise magnet alignment would be expected a few millimeter peak-to-peak or smaller.

In those three errors, the first error is able to correct before the beam commissioning by using the orbit and optics correction simulation on the model lattice containing the vertical tunnel displacement measured by the alignment works. By applying this pre orbit and optics correction to cure the long wave length tunnel distortion effect, the magnitude of the effective alignment error can be reduced by a factor of 10.

THE PRE ORBIT AND OPTICS CORRECTION METHOD

The pre correction parameters are determined by solving the linear equation which describes the perturbative relationship between the optical functions of the model lattice with the tunnel subsidence and the correction (steering and skew quadrupole) parameters of the model lattice, where the response matrix of this linear equation is calculated from the numerical derivative of the optical functions.

In the pre correction calculation on the simulation model, we have not to consider the measurement error of the beam instrument system and the limitation of the optical function reconstruction algorithm. In the calculation model, we can correct not only the vertical orbits y and the vertical dispersion functions η_y but also the coupling parameters (R1, R2, R3, R4) which can not be directly measured. The correction goal of the optical functions are defined by the design value on the beam position monitor located on the alignment reference curve.

Because the SuperKEKB tunnel subsidence is too big to find the closed-orbit by using Newton-Raphson method, the pre correction calculation is achieved by applying the adiabatic tunnel subsidence and the orbit-optics correction alternately. The nonlinear response of the optical functions against the tunnel subsidence is corrected by these subsidence-correction iterations.

The pre correction parameters for the phase-1 commissioning are determined by using the model lattice based on the measured vertical level of the beamline magnets analyzed at July 2015. The SVD tolerance for the orbit and optics correction is 10^{-3}. The modeling curve of the magnet level and the correction parameter distribution of the electron high energy ring (HER) obtained by the pre correction are shown in Fig. 2 with the distribution of the residual optical functions. In this model calculation, the rms of the residual vertical orbit and dispersion function at the BPMs are 112μm and 3.39mm, respectively. The predicted vertical emittance after the pre correction is about 1pm rad and is enough for the low emittance tuning study.

FIRST BEAM WITH PRE CORRECTION

At the first beam circulation of the SuperKEKB phase-1 commissioning, the pre orbit and optics correction parameters are applied to accelerator rings at the first beam injection tuning. In order to achieve one turn beam transportation from the injection point, steering bending magnets are adjusted to improve the transport distance of the beam charge measured by turn-by-turn beam position monitors(TbT BPMs). The first one turn beam transportation of the SuperKEKB high energy ring (HER) is achieved by adjusting only 6 horizontal and 1 vertical steering dipole magnets manually. The maximum kick angle of the adjusted steering magnets is 0.7mrad. This orbit tuning time to the first beam circulation is not so long compared with the beam tuning after long maintenance shutdowns in the latter half of the KEKB B-factory accelerator operation. Thus it is supposed that the pre orbit correction has an effect to help the first beam circulation tuning. But, it is not easy to determine quantitatively effect of the pre correction, because the time for the first beam circulation study is not enough to obtain the control group to estimate the effect of the pre correction.

SUMMARY

In the SuperKEKB construction, we did not correct the long wavelength vertical tunnel distortion to reduce the magnet alignment cost and time. To prevent the vertical closed-orbit distortion and the vertical emittance growth due to this long wavelength tunnel distortion, we apply the pre orbit and optics correction based on the magnet level measurement results at the SuperKEKB phase-1 commissioning.

The orbit tuning time to circulate beam into the SuperKEKB rings looks like short enough compared with the beam circulation after the long maintenance shutdown of the KEKB B-factory operation. It is difficult to estimate the saving time for the beam tuning by applying the pre correction because we have no orbit tuning sample without the pre correction. However, we do not observe an extra trouble due to the pre correction.

In the case that the precise magnet alignment measurement result and the orbit & optics correction tool are available, the newly required resource to determine the pre correction parameters is a tiny hack to convert the measured data to tool inputs and a tiny computing power. If an ideal alignment condition can not be prepared, it would be meaningful to try the pre orbit and optics correction based on the alignment measurement.

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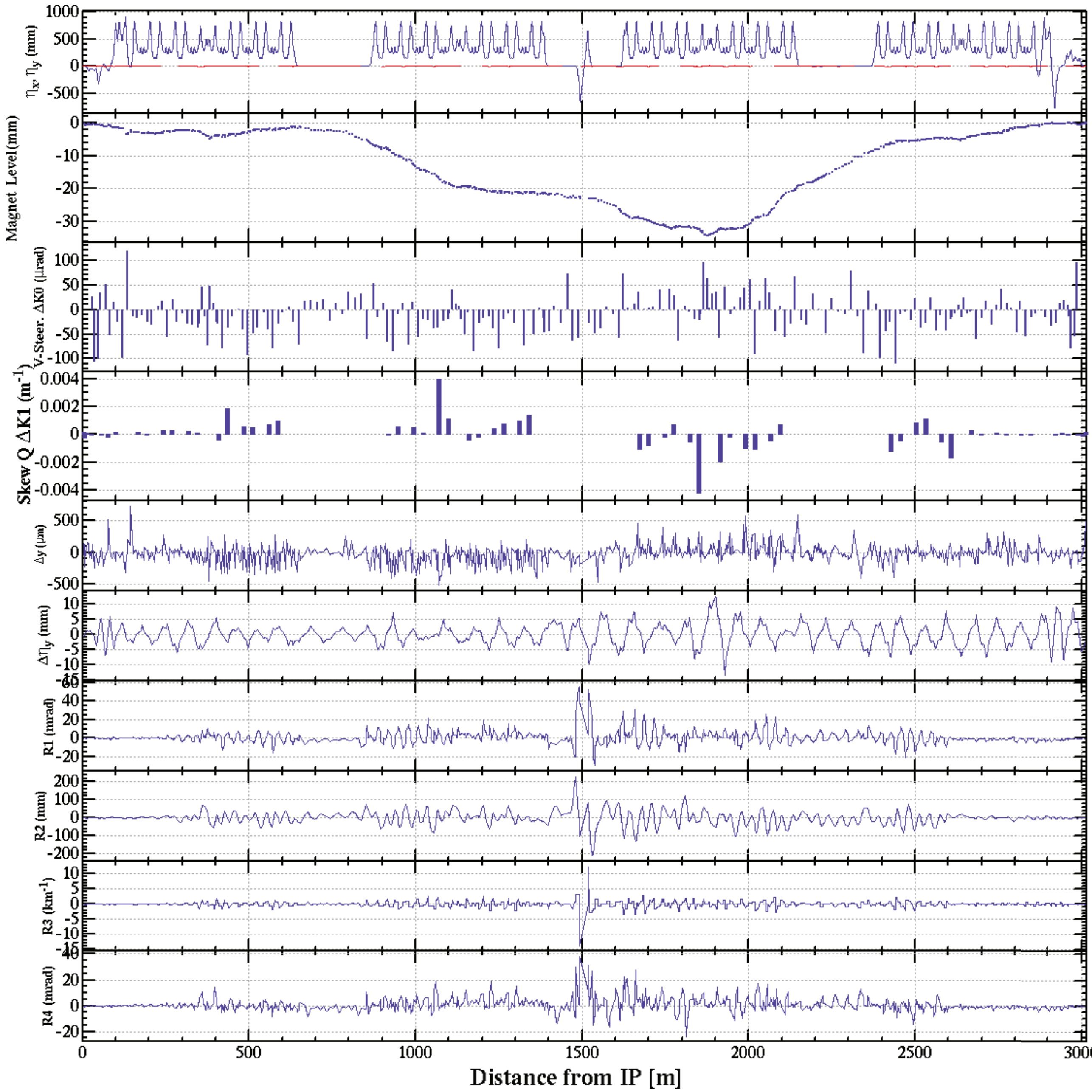

Figure 2: The optical function and the correction parameter distribution of the electron high energy ring (HER) after the pre correction. 1st column shows the dispersion functions corresponding with the arc sections. 2nd column shows the measured vertical level of the ring magnets. 3rd and 4th columns show the distribution of the vertical steering corrector and the skew quadrupole coupling-dispersion corrector, respectively. The following columns show the residual optical functions: vertical orbit, vertical dispersion function and coupling parameters (R1, R2, R3, R4), respectively.

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