FEL WIGGLER BUSSBAR FIELD COMPENSATION*

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Abstract

The Duke storage ring is a dedicated driver for the storage ring based free-electron laser (FEL) and the High Intensity Gamma-ray Source (HIGS). The high intensity gamma-ray beam is produced using Compton scattering between the electron and FEL photon beams. The beam displacement and angle at the collision point need to be maintained constant during the gamma-ray beam production. The magnetic field of the copper bussbars carrying the current to the FEL wigglers can impact the beam orbit. The compensation scheme in-general is complicated. In this work, we report preliminary results of a bussbar compensation scheme for one of the wiggler and power supply configurations. Significant reductions of the orbit distortions have been realized using this compensation.

INTRODUCTION

The Duke free electron storage ring is a dedicated driver for the storage ring based free-electron laser (FEL) [1] and the High Intensity Gamma-ray Source (HIGS) [2]. The facility operates three accelerators: (1) a 0.16–0.27 GeV linac pre-injector; (2) a 0.16–1.2 GeV full-energy, top-off booster injector; and (3) a 0.24–1.2 GeV electron storage ring [3]. The operation of the FEL system uses various configurations of the six available wigglers including two planar OK-4 wigglers and four helical OK-5 wigglers, located in the south straight section of the Duke storage ring. The nearly monochromatic gamma-ray beam is produced using Compton scattering between the electron beam and FEL photon beam. The electron beam orbit displacement and its angle at the collision point are two essential factors which can impact the quality of the gamma-ray beam.

The helical FEL system of the Duke storage ring can use up to four electromagnetic OK-5 wigglers which are powered by two power supplies, named TREX2 and TREX3, respectively. The upstream OK-5A and OK-5B wigglers share the use of power supply TREX3, the other two wigglers (OK-5C and OK-5D) share TREX2. The DC currents are carried to various wigglers using long copper bussbars with the longest ones running about 24 m under the beamline. The DC current induced direct bussbar magnetic fields can impact the beam orbit, therefore affecting the quality of the gamma-ray beam. To maintain a consistent e-beam orbit for a wide range of FEL wiggler currents and electron beam energies, the bussbar field needs to be properly compensated. Because a variety of the FEL wiggler configurations (see Fig. 1) are used, the field compensation scheme is complicated. As an example, the compensation scheme for one of the wiggler power supplies TREX2 which powers two downstream OK-5 wigglers (OK-5C and OK-5D) is described in this paper.

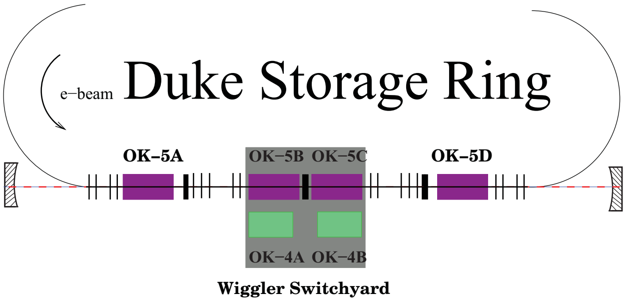

Figure 1: The schematic layout of the Duke FEL system with four helical OK-5 wigglers.

ORBIT COMPENSATION SCHEME

Consider a corrector at a location s_0, strength $\theta(s_0)$, the changes of the closed orbit at some other location s in the storage ring can be described as [4]

$$\Delta u_{\mathrm{co}} = G(s, s_0)\theta(s_0),$$

where u is the orbit change in either the horizontal or vertical direction, and the Green function of Hill's equation is $G(s, s_0) = \frac{\sqrt{\beta(s)\beta(s_0)}}{2\sin\pi\nu}\cos(\pi\nu - |\psi(s) - \psi(s_0)|)\,\theta(s_0)$, where β is the lattice betatron function, and ν is the betatron tune and ψ is the phase advance.

Let us consider a storage ring with N correctors and M beam position monitors (BPMs). The Green function between the i-th BPM and the j-th corrector is $G(s_i, s_j)$ denoted as a real response matrix element R_{ij}. The response matrix can be measured by recording the BPM readings while varying the strength of the correctors one by one.

The singular value decomposition (SVD) algorithm is used to decomposes the response matrix R into

$$R = U\Lambda V^T, \tag{1}$$

where V^T is a real orthogonal $N \times N$ matrix with $VV^T = V^T V = I$, Λ is a rectangular $M \times N$ matrix with non-negetive diagonal elements $\Lambda_{1,1} = \sqrt{\lambda_1}$, $\Lambda_{2,2} = \sqrt{\lambda_2}$..., and U is a real orthogonal $M \times M$ matrix with $U^T U = UU^T = I$ [4]. The real diagonal matrix Λ are ordered from the largest of the singular value to the smallest.

To keep the strengths of the correctors reasonably small while achieving an effective orbit correction, only a subset

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of the largest singular values are retained in the matrix Λ. For orbit change $\Delta\vec{u}$, the corresponding corrector strength can be expressed as

$$\Delta\vec{\theta} \quad = \quad R^{inv}\Delta\vec{u}, \qquad (2)$$

with $R^{inv} = V\Lambda^{inv}U^T$, where Λ^{inv} is a $N \times M$ matrix with $\Lambda^{inv}_{1,1} = 1/\sqrt{\lambda_1}$, $\Lambda^{inv}_{2,2} = 1/\sqrt{\lambda_2}$, ..., and all not-retained diagonal elements are 0. The number of singular values used in Λ will be determined empirically by examining the compromise between the strengths of the correctors and the residual orbit errors.

EFFECT OF BUSSBAR FIELD TO BEAM ORBIT

In Duke storage ring, the bussbar field can impact the beam orbit while the FEL system is running. To power the downstream OK-5C and OK-5D wigglers, power supply TREX2 is connected to these wigglers using copper bussbars under the beamline. In the routine operation, the power supply can provide a DC current between 0 and 3.5 kA, and the magnetic field from the current flow in the bussbar can alter the electron beam orbit.

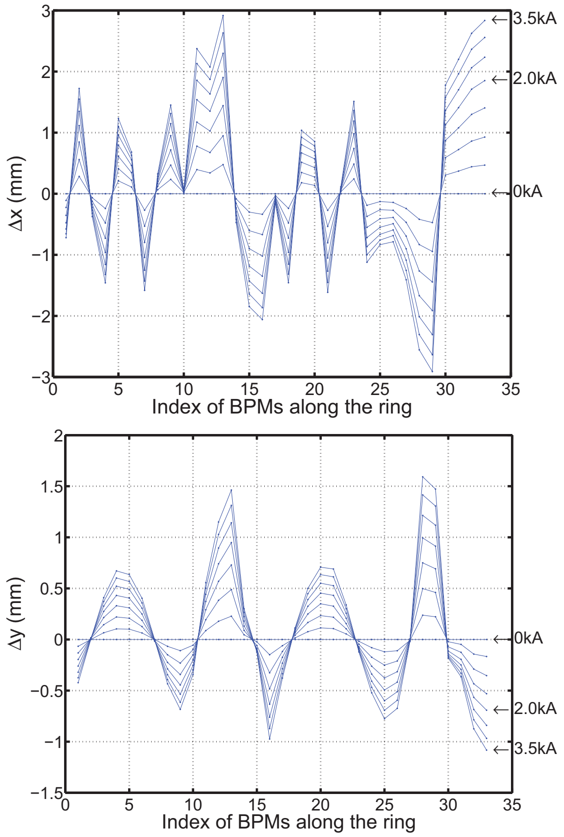

Figure 2: The measured beam orbit changes along the storage ring as a function of the wiggler current from 0 to 3.5 kA at 333 MeV e-beam energy.

The effect of the bussbar field on the beam orbit can be directly measured. For example, the beam orbit was measured with bath wigglers shorted while the TREX2 current is ramped from 0 to 3.5 kA. The change of the electron beam orbit was recorded using 33 BPMs distributed along the storage ring. The measured beam orbit changes relative to the values of zero wiggler current are shown in Fig. 2. At 3.5 kA, the maximum orbit differences are 2.916 mm in the horizontal direction and 1.592 mm in the vertical direction, respectively for a 333 MeV electron beam. The changes of the beam angle at the collision point were 0.50 mrad in the horizontal and 0.18 mrad in the vertical, respectively. Figure 3 shows the measured rms beam orbit change as a function of the wiggler current, marked by the blue asterisk. The maximum rms orbit changes are 1.653 mm in the horizontal direction and 0.709 mm in the vertical direction, respectively. In Fig. 3, the beam orbit changes are fit to a linear function of the wiggler currents in both horizontal and vertical directions with slopes of 0.501 mm/kA and 0.213 mm/kA, respectively. Therefore, a simple compensation can be developed to compensate the bussbar field effect.

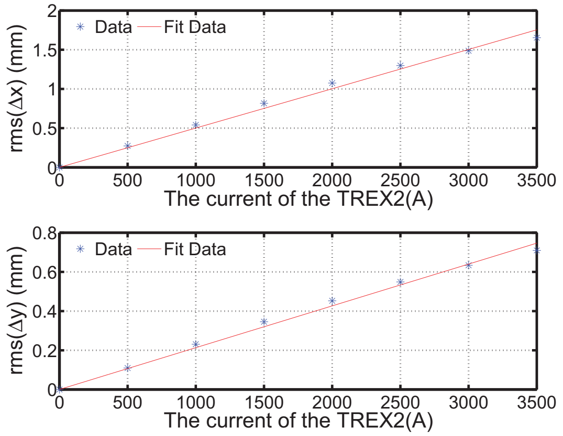

Figure 3: The rms beam orbit as a function of the wiggler currents from 0 to 3.5 kA at 333 MeV e-beam energy.

BUSSBAR FIELD COMPENSATION RESULTS

As the actual bussbar field distribution is unknown, the field compensation scheme is developed using the beam based method. First, the response matrix is measured between the locations of the BPMs and orbit correctors. As the bussbar field is distributed mainly in the region from OK-5C wiggler to the OK-5D wiggler, eight (8) correctors in the horizontal direction and seven (7) correctors in the vertical inside this area are used in the compensation scheme. The rms orbit changes (from 15 BPMs) in both straight sections of the Duke storage ring are minimized. The SVD algorithm is then used to obtain the corrector's strength for the compensation, which are shown in Fig. 4. The maximum corrector strength is 0.15 mrad in the horizontal and 0.20 mrad in the vertical.

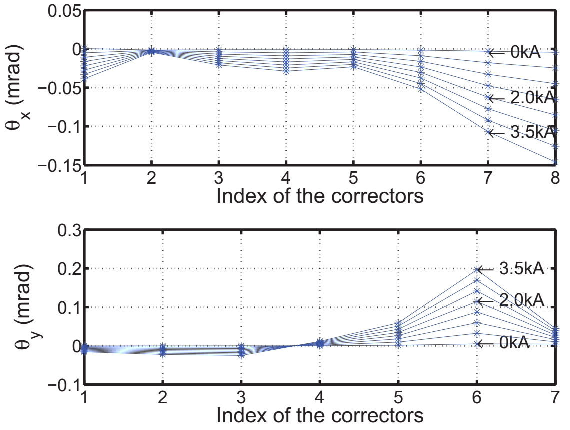

Figure 4: The strengths of the correctors used to compensate for the orbit errors with TREX2 at 333 MeV e-beam energy and 0 to 3.5 kA wigger current.

After applying the compensation, the measured beam orbits are depicted in Fig. 5, which shows that the max rms beam orbit changes are 0.087 mm in the horizontal and 0.041 mm in the vertical (see Fig. 6). After the compensation, the maximum beam angle changes at the collision point are 25 μrad in the horizontal and 11 μrad in the vertical.

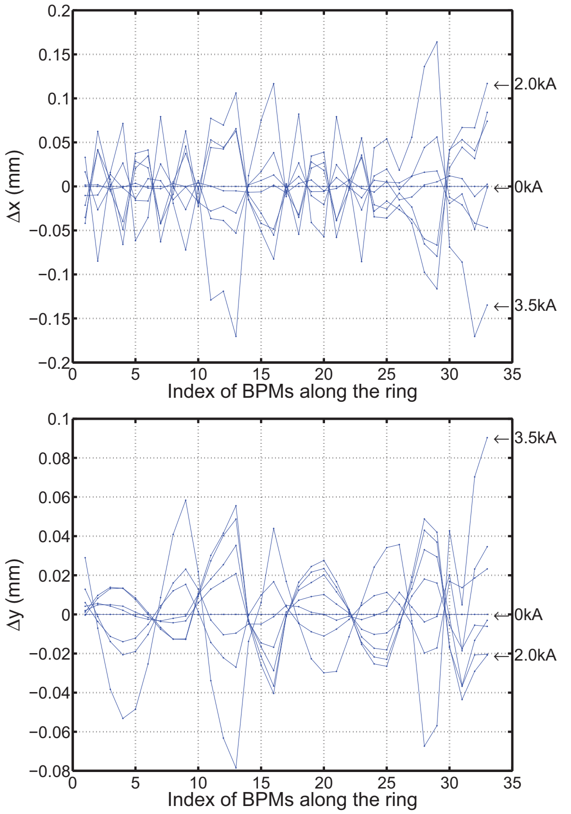

Figure 5: The beam orbit changes along the storage ring after applying the compensation. The measurement is on the condition of 0 to 3.5 kA wiggler current and 333 MeV e-beam energy.

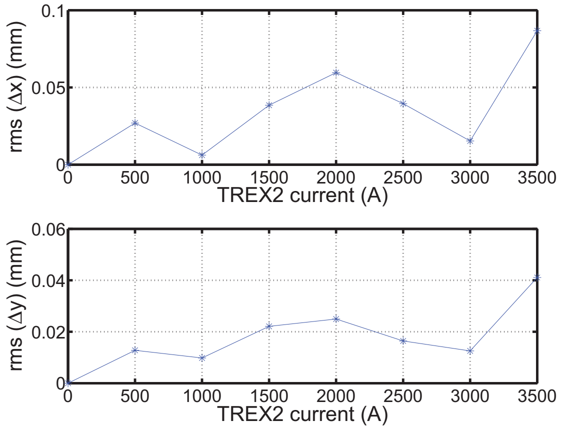

Figure 6: The rms beam orbit changes after applying the compensation as a function of the wiggler current from 0 A to 3.5 kA at 333 MeV e-beam energy.

SUMMARY AND ACKNOWLEDGE

The measurement results show that the beam orbit changed caused by the bussbar field can be effectively corrected using a 333 MeV electron beam. The rms orbit deviation are reduced by a factor of 19 and 17 in the horizontal and vertical directions, respectively. The rms residual orbit are 87 μm in the horizontal direction and 41 μm in the vertical direction at 3.5 kA, which is acceptable for the HIGS operation. The further optimization will be performed.

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