ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPM032

CROSS-TALK BETWEEN MAGNETS IN THE H6BA-CELL OF PETRA IV

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Abstract

For the upgrade of the 6 GeV synchrotron light source PETRA III into a diffraction-limited storage ring PETRA IV it is planned to replace the 23 m long double-bend achromats by hybrid six-bend achromats (H6BA). The high packing density of elements in the H6BA cells requires that the distances between magnets are small with only a few centimeters between the yokes for some of the magnets. Overlapping fringe fields of the magnets will result in substantial magnetic cross-talk. The change of the main field component of quadrupoles due to magnetic interference will lead to a change of the optical functions of PETRA IV. In this paper results of magnetic field cross-talk calculations between magnets will be presented. The influence of the cross-talk on the optics of PETRA IV, its integration in the lattice model and its correction will be discussed.

INTRODUCTION

PETRA III is a 6 GeV synchrotron light source at DESY that has been in operation since 2009 [1]. The lattice consists of double-bend achromats and FODO-cells and uses damping wigglers to achieve a natural emittance of 1.3 nm·rad. Replacement of the lattice by multi-bend achromats – as done recently for MAX IV [2] and ESRF-EBS [3] – would allow to reach extremely small emittances. For the PETRA IV project [4–6] it is planned to replace the lattice by hybrid six-bend achromats (H6BA). By using the additional radiation damping of damping wigglers, a natural emittance of 20 pm·rad can be achieved for small beam currents when intra-beam scattering is not contributing much to the emittance increase. If the undulators of the users are closed some of the damping wigglers have to be opened accordingly to keep the emittance constant.

PETRA IV Achromat

The length of the hybrid six-bend achromat of PETRA IV is rather short with 23 m and has a very compact design for the installation of magnets, undulators, vacuum components and beam diagnostics. In total, each achromat consists of 6 combined function magnets (with transverse and longitudinal gradient), 17 quadrupoles, 6 sextupoles, 4 octupoles, 5 fast/slow corrector magnets, and correction coils on sextupoles. As a consequence of the high packing density, the longitudinal distances between magnets are very small and fringe fields are overlapping. The smallest distance is only 47 mm which is comparable to the bore diameter of the quadrupoles of 22–25 mm. For such small distances between yokes of the strong magnets cross-talk is not negligible [7–9] and must be taken into account both for the magnet design and for the lattice model of PETRA IV.

In this study the cross-talk effect between magnets in the quadrupole triplets up- and downstream of the undulators was analyzed. These quadrupoles have the highest gradient in the achromat and will be operated near the saturation region of the excitation curve. It is therefore important to simulate the change of the integrated field gradients due to cross-talk.

CROSS-TALK IN THE TRIPLET

Quadrupole triplets near the undulator in the achromats are used to focus the beta functions to 2.2 m at the center of the undulator straight (Fig. 1). Besides the three quadrupoles PQA, PQB and PQC [10, 11] a combined horizontal and vertical plane corrector magnet (FC) is placed between PQB and PQC. The yoke of FC has an octupole-like geometry and will be used both for slow and fast orbit corrections. The parameters of the magnets in the triplet used for the simulation are listed in Table 1 and are typical values for the case when damping wigglers are closed.

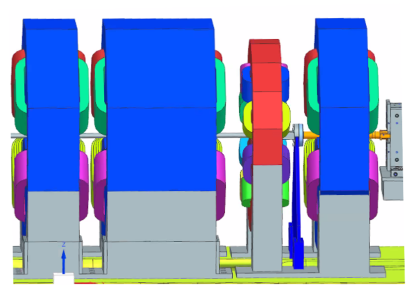

Figure 1: Layout of the magnets in the quadrupole triplet of the H6BA cell of PETRA IV.

Cross-Talk Simulations

To simulate the cross-talk between the magnets the magnetic field was computed both for each magnet and for the

Table 1: Parameters of the Magnets in the Triplet

Parameter	PQA	PQB	FC	PQC
Mag. length / mm	169	345	132	161
Iron length / mm	158	334	90	149
Gradient / T/m	-115.9	115.5	–	-85.9
Dipole field / T	–	–	0.14	–
Bore diameter / mm	22	22	25	25
Long. distance / mm	–/75	75/79	79/79	79/–

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assembly of several magnets. From the field difference between the two cases the effect of the cross-talk was determined. The magnetic fields were calculated using the program Opera-3D [12].

To simplify the computations, the problem was decomposed into the cross-talk in the PQA-PQB and PQB-FC-PQC assembly. For the quadrupole magnets the gradients mentioned in Table 1 were used. For the corrector a horizontal kick of 900 µrad and no vertical kick was assumed. From the field map the magnetic multipoles were calculated for a reference radius of 7.9 mm up to an order of 22 as a function of the longitudinal position with a step size of 1 mm. The multipole data were used to compute generalized gradients on a circular cylinder because of their insensitivity to numerical errors in the magnetic field data [13]. For this the program `computeCBGGE` from Elegant [14] was used.

Cross-talk between PQA and PQB

The longitudinal field profile of the quadrupole gradients on the beam axis of a single PQA (and PQB) is shown in Fig. 2 (red curve), and for the assembly of PQA-PQB (black). The difference between the gradient profiles for a single quadrupole PQA (and PQB) and the profile of the assembly of PQA-PQB is also shown (blue curve, multiplied by 10). Blue rectangles represent the yokes of PQA and PQB.

Both quadrupoles have a bore diameter of 22 mm and the distance between yokes is only 75 mm. For such a small distance the cross-talk is not negligible and changes the gradients in the body of the quadrupoles PQA and PQB by 0.8 T/m resp. −2.0 T/m. The integrated gradients are reduced by 1.0% for PQA and 1.8% for PQB. In addition, the gradient drops faster in the region between the quadrupoles compared to the range of the fringe field of a single quadrupole.

Such large gradient field errors will produce unacceptable large optics distortions without correction. As all quadrupoles of the H6BA cell will have individual power supplies, the reduction can be locally corrected by increasing the quadrupole currents accordingly. However, even after compensating the gradient reduction for the assembly of PQA-PQB (green curve, multiplied by 10) by taking the gradient reduction into account there remain some local uncompensated gradient errors. They appear mainly near the edges of the yokes of PQA and PQB.

Cross-talk between PQB, PQC and FC

Figure 3 shows the gradient profiles of the quadrupoles PQB and PQC, again for a single magnet (red) and for the assembly of all three magnets together (black). The blue rectangles are the yokes of PQB and PQC while the green rectangle is the yoke of the corrector FC. The corrector will be installed with equal distance of 79 mm to the nearby quadrupoles. While PQB has a bore diameter of 22 mm the PQC has a slightly larger bore diameter of 25 mm. For the magnet simulation only the coils were excited which are used for the horizontal slow corrector magnet.

For the quadrupole PQB the cross-talk with the corrector FC is a weak effect and produces almost no change of the gradient inside PQB. Some local gradient changes appear near the entrance edge of the yoke of the corrector FC. For the quadrupole PQC the cross-talk changes the gradient by 0.55 T/m and reduces the integrated gradient by 0.9%. Similar to the case of the quadrupoles PQA and PQB the gradient changes locally near the edges of the yokes of the quadrupoles and the correctors.

The quadrupoles PQB and PQC also have an effect on the dipole field of the corrector magnet FC (Fig. 4). While the field inside the corrector is mostly unchanged, the wide range of the fringe fields is shortened by the yokes of the nearby quadrupoles. This reduces the integrated field by 4.2%. Compared to a single FC most of the deviations of the dipole field appear near the edges of the nearby quadrupoles. Due to the symmetry of the distortion the center of the kick is still the center of the FC. The reduction of the corrector kick has to be taken into account in the calibration curve of the magnet. In addition, eddy currents in the magnets and vacuum chamber will modify the cross-talk at higher frequencies. This was investigated in a separate study [15].

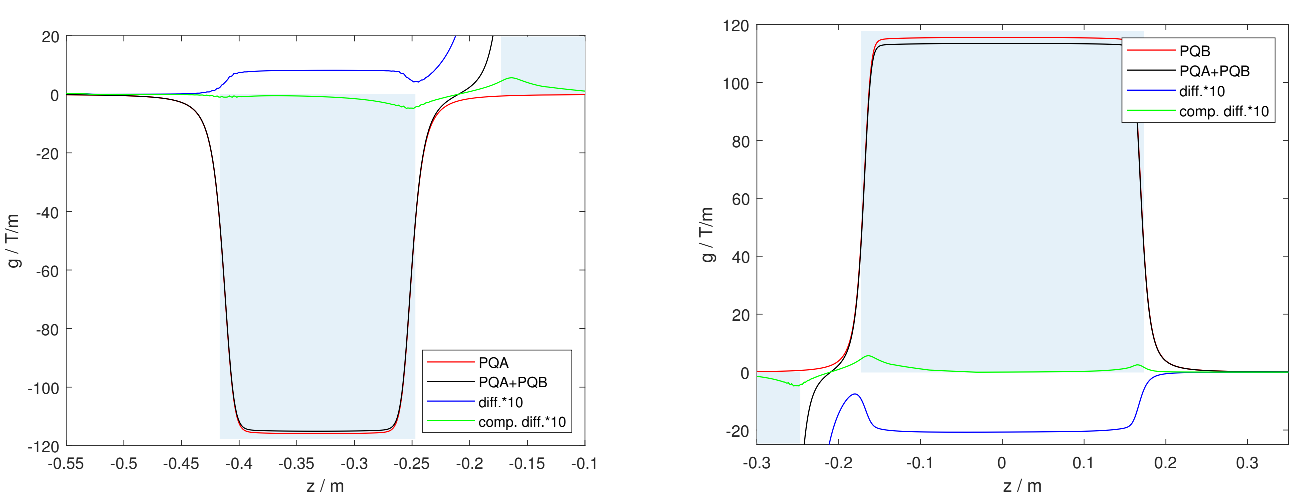

Figure 2: Change of the longitudinal gradient profile due to cross-talk between PQA (left) and PQB (right).

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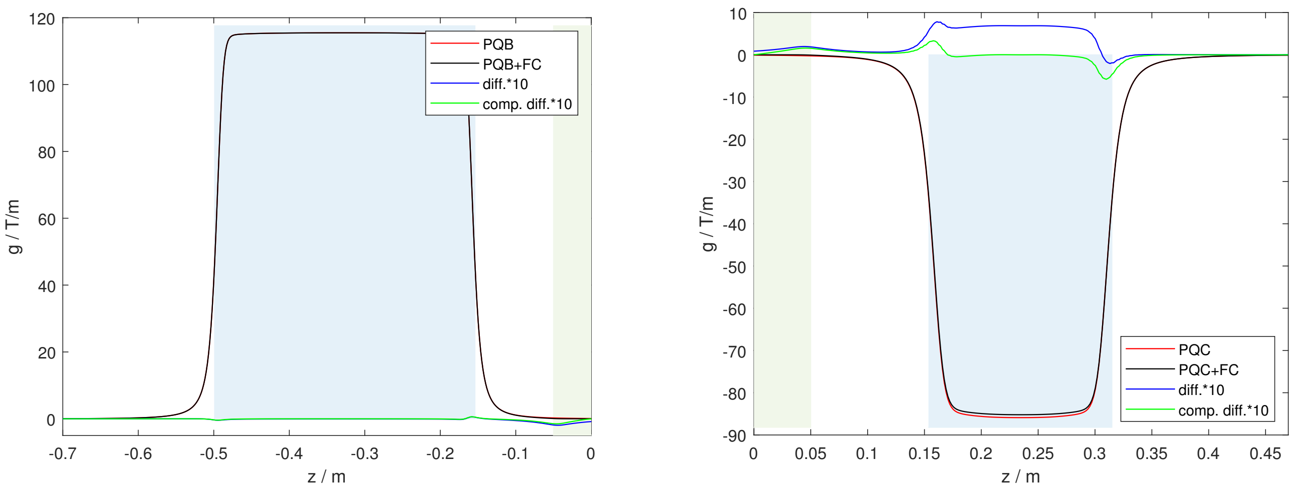

Figure 3: Change of the longitudinal gradient profile due to cross-talk between PQB (left), FC and PQC (right).

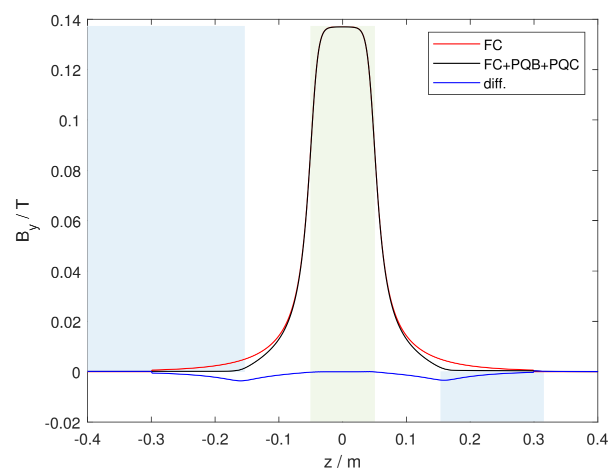

Figure 4: Change of the longitudinal dipole field profile due to cross-talk between PQB, FC and PQC.

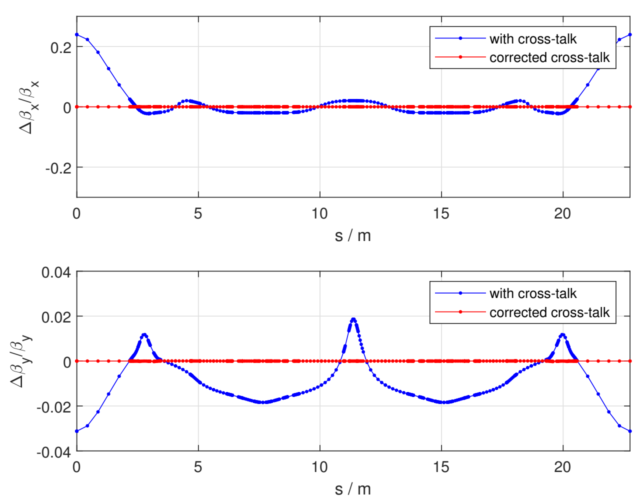

Figure 5: Beta-beating before (blue) and after (red) correction of the cross-talk effects in the quadrupole triplets of the H6BA cell.

CHANGE OF OPTICAL FUNCTIONS

The change of the optical functions in the H6BA cell due to cross-talk in the triplet magnets was computed in a simplified model by taking the gradient errors into account. The quadrupole strengths were reduced according to the reduction of the field integrals discussed in the previous section. The gradient errors near the edges of the quadrupoles and the corrector were simulated by adding thin quadrupole lenses at these locations. For this, the local gradient errors near the entrance and exit edges were integrated. Both gradient error sources were applied to the MAD-X [16] model of the H6BA cell. The H6BA cell with gradient errors was then used to match again the optical functions of the achromat. The beta-beating due to cross-talk in the achromat before (blue) and after the optics correction (red) is shown in Fig. 5. Without correction the beta-beating is about 20% in the horizontal plane and 3% in the vertical plane, but can be corrected. The necessary correction of the optical functions in both planes requires the increase of the quadrupoles strength by 1.8% for PQB and about 0.7% for PQA/PQC.

SUMMARY

Cross-talk between magnets in the quadrupole triplet of the H6BA cell of PETRA IV was investigated in this study. Simulations have shown that the integrated gradients of the quadrupoles will be reduced by up to 1.8%. Without any correction the beta-beating will be unacceptable large and reaching values of about 20%. Optics correction with the quadrupoles in the achromat can almost completely compensate the optics distortion. Further cross-talk computations between other multipole magnets in the achromat with much shorter distances between yokes are foreseen and will be done in future studies.

ACKNOWLEDGEMENTS

The author would like to thank S. Liuzzo from ESRF for discussions about the implementation of cross-talk effects in the ESRF-EBS lattice model.

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