OPTICS ADAPTATIONS FOR BENDING MAGNET BEAM LINES AT ESRF: SHORT BEND, 2-POLE WIGGLER, 3-POLE WIGGLER

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Abstract

The ESRF-EBS project [1] [2] foresees the replacement of the existing bending magnets beamlines with different radiation sources: short bend, 2-pole wiggler or 3-pole wiggler. After describing the reasons for these choices the required modifications to the storage ring lattice are described in details for each case. The study of the impact of lattice errors is also addressed, leading to the definition of beamlines' alignment tolerances.

INTRODUCTION

In 2020 the ESRF storage ring will be replaced by 32 Hybrid Multi Bend Achromatic (HMBA) lattice cells shown in Fig. 1.

The ESRF is currently providing X-rays from undulators installed in 28 of the 32 straight sections (ID) and from 16 bending magnets (BM). An equivalent of the latter will not be possible for the ESRF-EBS upgrade, as the DQ magnets (see Fig. 1) have a field of 0.55 T, compared to the present 0.86 T used for the BM sources. The current ESRF storage ring BM dipoles have a larger gap towards the center of the cell to provide soft or hard X-ray according to the angular position of the beamlines. Figure 2 shows the fan of radiation produced by this two sources.

Several solutions have been studied to include in the EBS upgrade a radiation source suitable for the BM beamlines. The drift space between DQ2C and QF8D in the arc cell (see Fig. 1) is at the correct angular location to provide beam through the existing hard-edge BM beam port. The solutions envisioned to replace the BM sources are:

- radiation from the combined-function magnets (DQ2C or DQ1D, accepting the field reduction),
- a three-pole wiggler (3PW) ($\Delta\epsilon_x = 0.0$ pm each),
- a two-pole wiggler (2PW) ($\Delta\epsilon_x = 0.07$ pm each) and
- a short bending magnet (SB) ($\Delta\epsilon_x = 0.24$ pm each).

These solutions have different photon beam characteristics and each beamline has chosen the most suitable for their experiments [3]. All solutions have peak field of 0.86 T to cope with the existing front-end shielding. However, the solutions are ordered in increasing requirement for local lattice adjustments. The DQ and 3PW solutions have no impact on the standard cell layout. On the other hand, the 2PW and SB solution require significant local modifications to the lattice cell.

According to the needs of the beamlines, seven SB, eight 2PW and one 3PW will be installed in the EBS storage ring. None of the beamlines could accept the properties of the radiation produced by the DQ magnets.

The fan of radiation produced by the future EBS sources is compared to the one presently available in Fig. 2.

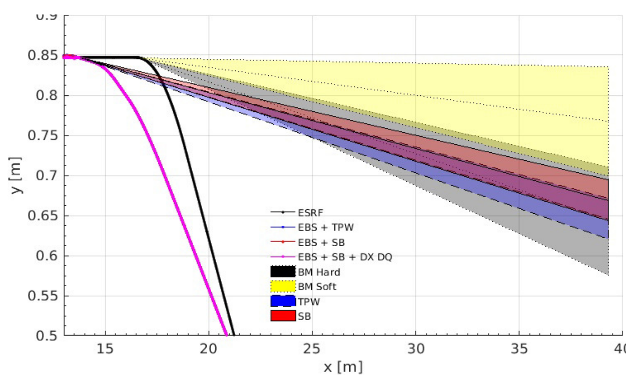

Figure 2: Radiation fan for the current ESRF soft and hard bending magnet sources and for the 3-pole wiggler (TPW) and Short Bend (SB) sources in the EBS upgrade.

Two-Pole Wiggler

Using the 2PW solution the closed orbit is displaced by about 90 µm after the source (see Fig. 3). The offset trajectory can be recovered in several ways: using the correctors magnets, introducing an additional unbalance in the poles of the 2PW to reduce the stress on the correctors or by tilting and displacing the QF8 quadrupole. The last of these options is shown in Fig. 3. The required tilt about the vertical axis

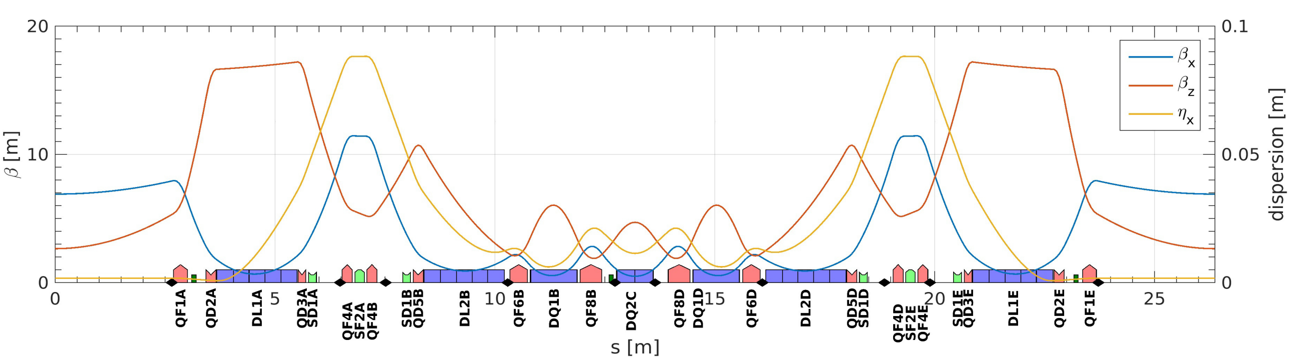

Figure 1: HMBA Lattice cell optics and layout, formerly Hybrid multi bend achromat.

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is −1.76 mrad and the displacement is 44 µm. The required displacement is very similar to the alignment tolerances for the QF8 quadrupoles ($\sigma_{x,y}$ = 50 µm).

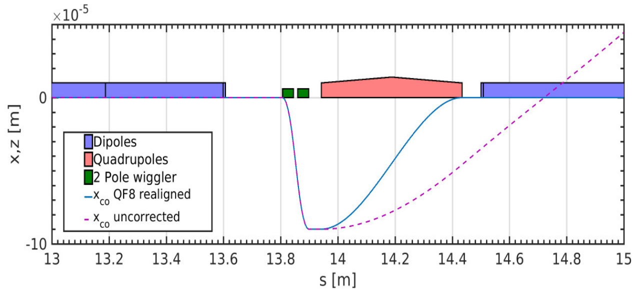

Figure 3: Impact of the 2PW on closed orbit, restored tilting about the vertical axis the near by QF8 quadrupole.

Short Bending Magnet

The SB dipole has a total bending angle of about 2.12 mrad, which needs to be removed from the other dipoles in the cell to ensure constant total angle. The modification of the bending angles changes the reference trajectory and thus defines new positions in space for the magnets of the cell. An accurate choice of bending angles allows to limit the magnets to be realigned. In Fig. 4, three cases are compared to the standard EBS cell layout:

1) **Only the SB is added:** total angle is incorrect and lattice geometry is not closed.
2) **DQ2C and DQ1D bending angles reduced by half of the value of the SB bending angle:** the total angle is correct but the reference trajectory is translated. The lattice geometry is non closed.
3) **DQ1B DQ2C and DQ1D bending angles are varied independently to match the reference trajectory after DQ1D:** the lattice geometry is recovered after DQ1D. A new reference position is defined also for QF8B and QF8D (angle and position re-alignement).

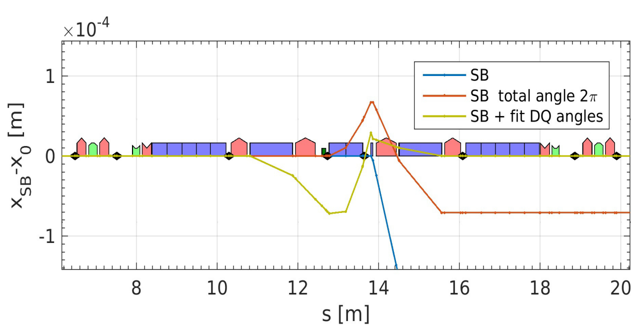

Figure 4: Impact of the SB on magnets survey, restored changing the bending angles of the the near by dipole magnets.

In order to avoid the overlap of the radiation fans from DQ1 or DQ2 and the source devices, the bending angle along the cell is forced to be always positive in 3). The angle along the longitudinal coordinate s is shown in Fig. 5.

The DQ1 and DQ2 dipole fields can be modified by a radial displacement (about the new reference trajectory) taking advantage of the quadrupole field component. To reduce the field of a DQ1 magnet by 1 mrad the simple relation $\Delta x = \Delta\theta \cdot K_{DQ1}$ leads to $\Delta x = -547\mu m$, while tracking using a magnetic-length model gives a value of $\Delta x = -642\mu m$ is found. The exact required displacement will be determined after magnetic measurements.

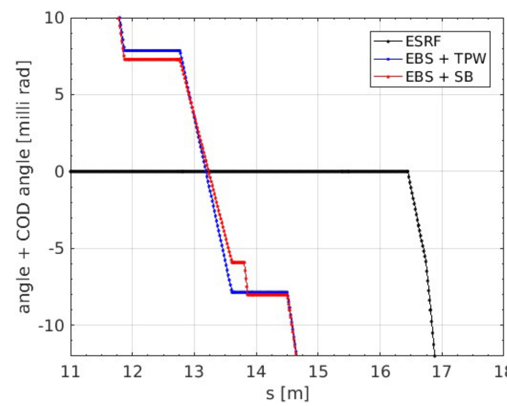

Figure 5: Lattice curvature about the BM source. The angle is constantly increasing allowing angular discrimination of the source points.

Figure 6 shows a detail of Fig. 2, revealing the new magnet positions. The necessary field reduction is implemented by a further alignment of the DQ magnets. This realignment is approximated in Fig. 2 to display the real requested position modification for the magnets. The necessary alignment modifications are within the adjustment possibility of the supports of the magnets.

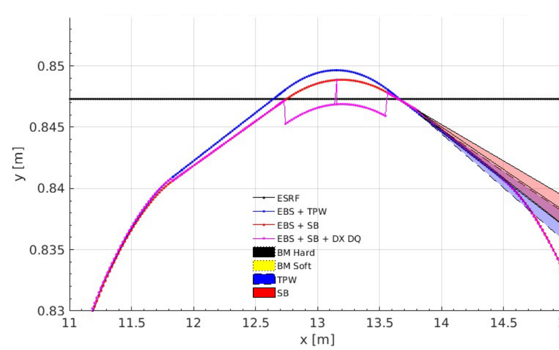

Figure 6: Lattice layout modifications for the installation of a SB.

The change in bending angle introduces also a modulation in the horizontal dispersion, as shown in Fig. 7. There are several possibilities to correct this modulation, and the most effective is to unbalance the gradients of the

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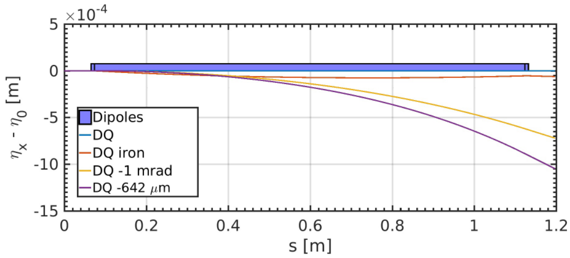

Figure 7: Dispersion modulation in a displaced DQ or in a reduced angle DQ compared to the standard cell (magnetic lengths).

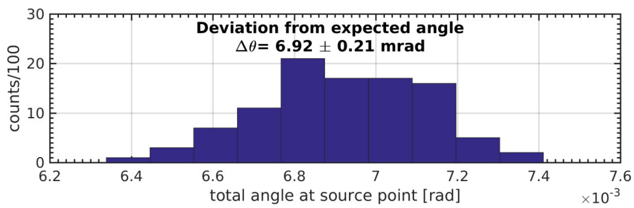

Figure 8: Angle at source point for 100 seeds of errors.

QF4 quadrupoles (see Fig. 1) by $0.000\,48\,\mathrm{m}^{-2}$ (0.02%) on the left (+) and right (-) of the SB.

The impact of the above solutions on dynamic aperture and lifetime is given in [4].

Alignment errors Lattice alignment errors are considered to determine an error on the required realignment of the SB beamlines. Random errors are simulated and corrected for 100 seeds of errors (error list as in the Technical Design Study [2]), and for each seed we consider the sum of the bending angle and the closed orbit angle at the source point. The center of the SB radiation fan will be at 6.92 ± 0.21mrad (see Fig. 8).

Considerations on SB lattice model The quantification of the lattice adaptations to include the SB in the lattice depends on the model used to describe the magnets (magnetic lengths in our case) and on the technique used to evaluate the distortions. The latest can be either of: 1) a change of bending angle (and thus a change of reference trajectory without any closed orbit distortion) or 2) a misalignment error in the lattice (affecting only closed orbit distortion). The first option has been used for the data presented above and will be the solution used during commissioning. The second option has also been studied: five magnets (DQ1B DQ2C DQ1D QF8B and QF8D) have been displaced radially and independently to close the orbit bump and minimize dispersion modulation. Figure 9 shows one of the solutions obtained with this model, set to cancel the angular distortion at the SB (same angle as for a 3-pole wiggler source). With this solution the radius of curvature becomes negative before the SB, leading to a radiation fan overlap with the DQ2C dipole. The solution obtained requires only radial displacements compared to the standard cell of less than $350\,\mu$m

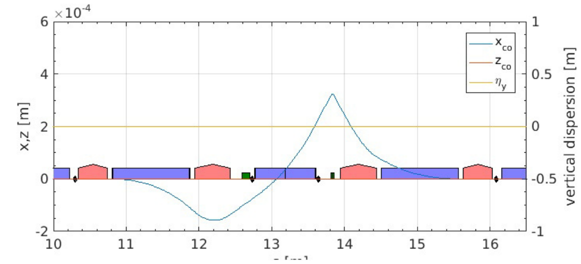

Figure 9: SB lattice adaptation using only radial magnet displacements, without changes in the main dipole fields.

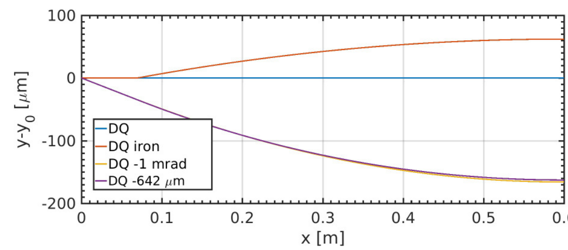

Figure 10: e^- trajectory in a displaced DQ or in a reduced angle DQ compared to the standard cell (magnetic lengths).

for all the five magnets involved: DQ1B: $90\,\mu$m, DQ2C: $-212\,\mu$m, DQ1D: $-62\,\mu$m, QF6B: $51\,\mu$m, QF6D: $330\,\mu$m.

The description in terms of dipole bending angle is not fully realistic as it assumes a modified curvature for the DQs, although those will be only realigned and their curvature is machined to the nominal values of the standard cell[1]. The variation of trajectory is depicted in Fig. 10 for the case of a DQ with angle reduced by 1 mrad and for the equivalent misalignment. The difference is of $\sim 4\,\mu$m at the center of the DQ (0.6 m in Fig. 10). The difference between the two models becomes more significant in terms of dispersion modulation as shown in Fig. 7. This difference originates from the different dipole fields seen by the e^- inside a DQ1 either misaligned or with reduced field and by the different reference trajectory. The dispersion modulation will be optimized experimentally using the QF4 quadrupoles as described above.

ACKNOWLEDGMENT

All optics simulations are performed using Accelerator Toolbox [5].

CONCLUSION

The solutions to produce radiation suitable for the EBS upgrade BM beamlines are presented and require local modifications of the lattice cells. The introduction of 3-pole wigglers and 2-pole wigglers demands none or few modifications, while significant changes in the lattice layout are necessary for the installation of SB sources. During the commissioning of the EBS, these magnets will be installed in a later phase as modifications to the main lattice.

[1] Note that due to magnetic length the curvature of the iron for the DQ is not exactly the curvature of the electron trajectory in the magnet

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