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BESSY III STATUS REPORT AND LATTICE DESIGN PROCESS

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Abstract

Since 2020 a detailed discussion about a BESSY II successor is ongoing at Helmholtz Center Berlin (HZB) and its user community in order to define the science and layout of the new facility. Still free locations close to BESSY II have triggered a discussion about a greenfield project, but in-house upgrade solutions have also been investigated. As a special boundary condition, BESSY III has to meet the requirement of the Physikalische Technische Bundesanstalt (PTB) for radiation sources for metrology applications and bending magnet sources for tender X-rays. A Conceptional Design Report is in preparation. Here, we give a status report including a first parameter space, technical specifications and a first candidate for the linear lattice.

THE BESSY III REQUIREMENTS & OBJECTIVES

A first sketch of the upgrade discussion of BESSY II with its user community and the envisaged parameter space has been given in [1] and is briefly summarized in Table 1. The main objectives and also largest changes compared to BESSY II are the increase of energy up to 2.5 GeV and the decrease of emittance down to 100 pm rad, motivated by the science case request for diffraction limited radiation with adjustable polarisation up to 1 keV photon energy from the 1st undulator harmonics.

Table 1: Main Parameters of BESSY II and BESSY III

Parameter	BESSY II	BESSY III
Energy	1.7 GeV	2.5 GeV
Circumference	240 m	~ 350 m
# of straights	16 with 5.0 m	≥ 16 with 5.6 m
Emittance ϵ_0	5 nm rad	100 pm rad
$\beta_{x,y}$ in straights	(1.2, 1.2) m	< (3, 3) m
mom. comp. α_p	7.0e-4	> 1.0e-4

Further demands on the lattice are under discussion. For example, small $\beta_{x,y}$ functions of < 3 m in straights and the operation of round beam in order to match the electron beam and photon beam phase space within the undulators. And the momentum compaction α_p was chosen to be $>1.0 \times 10^{-4}$ in order to achieve reasonable bunch length and lifetime and not be dominated by collective effects. Owing to capacity reasons, at least one bending magnet source within the sector is also needed to deliver radiation in the soft-to-tender range, e.g., 1 keV to 10 keV.

The developments on "TRIBs / Two orbit operation" over the last years at BESSY II [2, 3] motivate the task to study such beam optics and operation scheme for BESSY III and investigate the impact on the achievable parameters compared to a standard user mode with one orbit [4].

Due to the long standing partnership since BESSY I (1981) with the PTB, Germany's national institute for standards & metrology, an absolutely mandatory demand on the BESSY III facility is to provide a radiation source, usable as primary radiation standard, i.e., an absolute, predictable and traceable radiation source for metrology purposes. For that the deflecting, magnetic field around the source point has to be known to highest precision and be accessible for a NMR probe measurement. As the measurement sensor itself has certain spatial dimensions of (10 x 10 x 10) mm^3 volume, a purely homogeneous magnet field is required at least for this volume or along the orbit of the electron beam. This is best realized with a purely homogeneous dipole magnet, which has to be included in the lattice. A combined function bend with gradient, i.e., changing magnetic field in the horizontal plane, which is often used in the mulitbend-achromat (MBA) unit cell, is therefore not a good choice. The request for the **homogeneous metrology bend** strongly influenced our lattice design process towards a first baseline lattice, which will be mainly discussed in this contribution.

THE BESSY III LATTICE DESIGN APPROACH

The development process towards a first baseline lattice for BESSY III could be broken down into three steps, which will be explained in the following.

- First tries, technical limitations & the choice for a Higher Order Achromat (HOA),
- 1st milestone lattice: "Simplest HOA" with only two chromatic sextupole families and integer tunes,
- 2nd milestone lattice: first non-linear optimization.

First Tries, Technical Limitations & HOA

First lattice attempts like a 16-period 9MBA based on the ALS-U design or a 18-period 5MBA resulted in very ambitious magnetic specifications, which have triggered a discussion about the hardware limits and technical realization. Within the CDR phase, the decision has been made to follow a more conservative ansatz and rely on already existing magnet technology, e.g., conventional state-of-the-art iron yoke electromagnet technology for multipoles. The CDR magnet specifications have not been driven to technical limits, and are listed in Table 2. Sticking to the technical limits and keeping the circumference of ~350 m a 6MBA compared to 7- or 8MBA seems to be the best solution in respect to emittance and the momentum compaction factor. The 5MBA does not allow to implement a HOA with strong

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Table 2: Technical Limits for Magnets

Magnet type	Max. Value
homogeneous dipole magnet	< 1.3 T
combined fct. bend (2 pole)	< 0.8 T and 15 T/m
combined fct. bend (4 pole)	< 0.8 T and 30 T/m
quadrupole	< 80 T/m
sextupole	< 4000 T/m
minimum spacing	0.1 m
bore diameter	25 mm
vacuum pipe diameter	18 mm

focusing, i.e., the horizontal tune of $q_x = 0.5$ would drive the β_x function towards zero within the main bend of the MBA unit cell, giving no stable solution and a phase advance of $q_x = 0.25$ does not reach the envisaged emittance.

In order to deliver a robust design with good control of non-linear beam dynamics, also with regards to TRIBs operation close to a 3rd resonance, **we chose the Higher Order Achromat (HOA) approach**, fixing the phase advance between the two chromatic sextupole families within the MBA unit cell.

Due to symmetry reasons, we decided to include the homogeneous metrology bend right from the beginning in the MBA structure to have 16 completely symmetric cells as starting point. In principle, there are then two configurations, shown in Fig. 1, how the metrology bend can be implemented in a MBA structure.

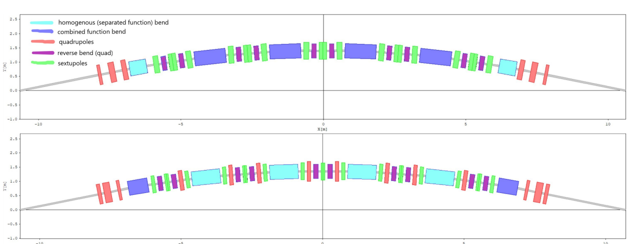

Figure 1: Combined function (CF) MBA unit cell lattice and separated function (SF) (bottom).

In the upper plot the homogeneous bend (or separated function bend (SF)) is placed at the beginning and end of the MBA structure as matching bend. The inner unit cells of the MBA structure are set up with combined function bends (CF) as mainly used in most MBA lattices. In the bottom plot the configuration is swapped. The inner unit cell bends are homogeneous SF bends and the outer matching bend is realised with vertical focusing as CF bend. Both lattices have been set up, investigated and compared in detail.

All HO-MBA lattices consists of the same building blocks: the central MBA unit cell (UC) with main bend, two chromatic sextupoles and vertical and horizontal focusing, the horizontal one as reverse bend; the dispersion suppression cell (DSC), which is mainly a slightly modified half unit cell with the purpose to take out the dispersion for the straight, and finally the matching cell (MC), i.e., the straight with quadrupol doublet or triplet to shape the $\beta_{x,y}$ functions within the ID and set the tune.

In order to set up the optics for the two lattices presented in Fig. 1, we carefully investigated all three basic building blocks (UC, DSC, MC) under the same constraints to come up with the most reasonable solution.

1st Milestone Lattice - Linear Beam Dynamics

In a first step, we set up our 1st milestone lattices following strictly the HOA approach. That means that the phase advance for the MBA UC was chosen to be $q_{x,y}(\mathrm{UC}) = (0.4, 0.1)$, resulting for a 6MBA with 5 unit cells in a phase advance of (2.0, 0.5). The phase advance of the section was chosen to be (2.75, 0.8125) to achieve an integer tunes for the whole ring of (44,13) in order to cancel all higher order resonance driving terms. The two families of chromatic sextupoles have been used to fit the chromaticity to zero.

By sticking to this strict constraints both lattice types could be set up in best way and compared in detail. Here we will only discuss some findings about the UC, depicted in Fig. 2, whereas more detailed explanation about the basic design choices for the BESSY III MBA lattice can be found in [5]. Setting up the unit cell by equally distributed bending

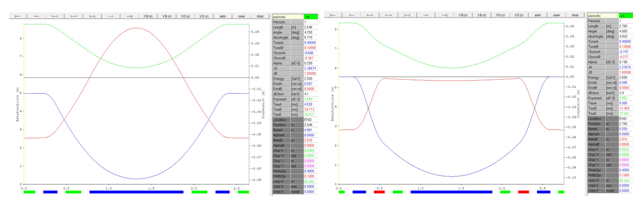

Figure 2: UC for the CF (left) and SF (right) lattice.

angles between UC and DSC, have not allow to reach the ϵ_0 value and α_p factor defined in Table 1. The impact on ϵ_0 and α_p of the reverse bend have been studied for both lattice types, shown in Fig.3. Due to the additional length given by

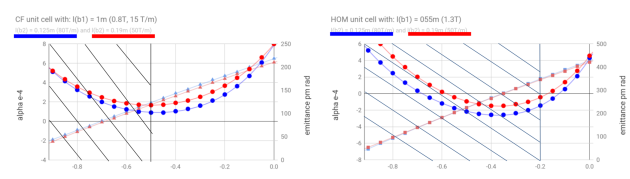

Figure 3: Impact of reverse bend on emittance and momentum compaction factor for CF (left) and SF (right) lattice.

the DSC and MC, the momentum compaction factor for the UC has to be ~ 2.0×10^{-4} for the UC, to achieve an overall value of 1.0×10^{-4}, which limits the reachable emittance. By increasing the main bending length (reducing the bending field) or decreasing the bending angle the emittance goal could be achieved. For 16 straights, a section need to bend by 22.5°, with a 6 MBA structure the matching bends with 2*2.25° and the main UC bends with 4*4.5°. In order to reach the emittance of 100 pm rad, the bending angle for the UC was decreased in the CF lattice down to 4.25° and for the SF lattice down to 4.0° with magnetic field of 0.6 T to 0.8 T.

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Another important point was the arrangement of the different magnet types within the UC. For the CF lattice only one permutation is possible. The horizontal focusing reverse bend can be switched with the mainly horizontal correcting sextupole, i.e., the outer one, so that the sextupoles would be positioned next to each other. In this case the main parameters (UC length, emittance, momentum compaction factor) change only by a few % whereas the integrated sextupole strength needed to fit the chromatity to zero is increased by 25%. The arrangement for both UCs (CF, SF) have been chosen in this way that the sextupole strength to correct the natural chormaticity is minimised in order to introduce non-linear magnetic fields as little as possible.

The best arrangement for the SF lattice is shown in Fig. 2. Compared to the CF lattice, it is worth to mention, that the mainly vertical correcting sextupole is close the main bend instead of the vertical focusing quadrupole. An interesting result is that the integrated sextupole strength for the SF lattice and so the sextupole length is reduced by 50% compared to the CF lattice due to better β functions and dispersion at the positions of the sextupoles. The UCs are nearly equal in length. The space saved with the combined function bend is lost due to the larger chromatic sextupoles in the CF case.

For 3rd generation lightsources a CF lattice could achieve a factor two smaller emittance, $\epsilon_0 = C_q \gamma^2 \frac{I5}{j_x I2}$, compared to a SF lattice due to the increased damping partion number j_x. With the introduction of the reverse bend by the SLS2, which also increases j_x, same emittances become accessible with an SF lattice with less integrated sextupole strength at nearly same length.

2nd Milestone Lattice - Non-linear Dynamics

So far the 1st milestone lattice has still integer tunes and is not optimised for non-linear beam dynamics. With our first non-linear optimisation we tried to confine the tune shift with momentum (TSWM) as well as with amplitude (TSWA). The TSWM is shown for both lattices in Fig. 4 in dashed lines for only two chromatic sextupole families and in solid lines with individual sextupole strength. The idea was to use the existing non-linear elements, i.e., the chromatic sextupoles, before introducing further elements. Therefore another non-integer working point was chosen and the chromatic sextupoles have been splitted. For the CF lattice the innermost sextupole has the biggest impact on the TSWM, whereas for the SF lattice it is the outermost. By treating all sextupoles individually, the TSWM could be reduced for the CF lattice from $\Delta q_x = 0.45$ down to 0.16 at $\Delta p/p = 4\%$ and for the SF lattice the TSWM could be reduced from $\Delta q_x = 0.32$ down to 0.05. Currently the impact of harmonic octuples is under investigation for the control of the TSWA. The aim is to reach a tune confinement or TSWM and TSWA behaviour similar to MAX IV or SLS2.0. The first baseline lattices are shown in Fig. 5, both with a circumference of ~ 350 m, emittance of 100 pm rad and α_p of 1.1×10^{-4}. The TSWM and TSWA indicate an advantages for the SF lattice with respect to non-linear dynamics.

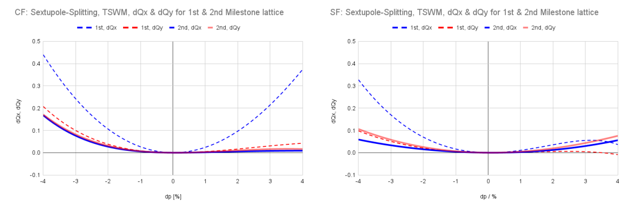

Figure 4: TSWM for CF and SF lattice for 1st (two chromatic sextupole families) and 2nd milestone lattice (individual chromatic sextupoles).

All lattice studies presented here have been done with OPA

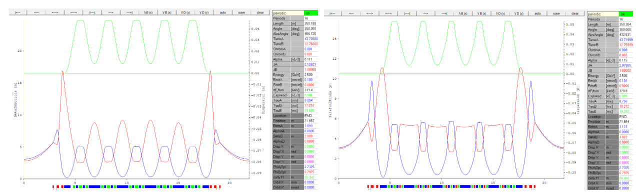

Figure 5: First baseline lattices for BESSY III.

(great tool!). Misalignment and tolerance studies will follow soon to verify the robustness of both lattices and further optimise the non-linear behavior with more sophisticate tracking software as TRACY, elegant or madx.

SUMMARY & CONCLUSIONS

A first baseline BESSY III lattice have been developed by a deterministic lattice design approach. The basic building blocks of a MBA lattice (UC, DSC, MC) have been studied carefully and combined to a robust sector cell (LEGO appraoch) with reverse bend. The lattice with a homogeneous bend in the UC reaches similar parameters than with a combined function bend.

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