SOLARIS STORAGE RING LATTICE OPTIMISATION WITH STRONG INSERTION DEVICES*

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Abstract

The Solaris synchrotron radiation facility under construction in Krakow will be a replica of the 1.5 GeV storage ring of MAX IV. This compact 3rd generation light source has been designed to have an emittance of 6 nm-rad and operate with 500 mA stored current for VUV and and soft X-ray production.The lattice consists of 12 double-bend achromats (DBA) where each DBA cell is integrated into one solid iron block. Twelve 3.5 m long straight sections are available of which 10 will be equipped with various insertion devices. These devices will differ from those adopted by MAX IV. For X-ray production one or more superconducting wigglers will be used, while APPLE-II type undulators will be used for variable polarised light production. The linear and nonlinear beam dynamics have been studied with these perturbing insertion devices included in the lattice and results are presented in this paper.

INTRODUCTION

The Solaris synchrotron radiation facility under construction in Krakow will be a replica of the 1.5 GeV storage ring of MAX IV. This compact 3rd generation light source has been designed to have an emittance of 6 nm-rad and operate with 500 mA stored current for VUV and and soft X-ray production.The lattice consists of 12 double-bend achromats (DBA) where each DBA cell is integrated into one solid iron block. Twelve 3.5 m long straight sections are available of which 10 will be equipped with various insertion devices. These devices will differ from those adopted by MAX IV. For X-ray production one or more superconducting wigglers will be used, while APPLE-II type undulators will be used for variable polarised light production.

BARE LATTICE OPTICS

The compact magnet design makes use of three horizontally focusing quadrupoles. The vertical focusing is achieved by the gradient in the dipoles. To have a possibility to tune the vertical gradient pole-face strips are installed on the bending magnets. The pole-face strips are under design and it is essential to determine the tuning range that is required in order to compensate for the various insertion devices. The focusing sextupoles have also been integrated into the focusing quadrupoles. In each magnet block there will be three beam position monitors (BPMs) and three horizontal/vertical corrector coils mounted on the sextupole magnets. Two of the BPMs will be positioned at the ends of the achromatic block and one in the centre [1]. Recently the lattice for the Solaris/MAX IV 1.5 GeV storage ring has been updated. The new lattice m5-20120313-521 makes use of a slice model for the magnets. The detailed description of the modification can be found in [2, 3]. The main parameters of the storage ring are displayed in Table 1.

Table 1: Main 1.5 GeV Storage Ring Parameters

Circumference /m	96
Circulating current /mA	500
Periodicity	12
Straight section's length /m	3.5
Tune hor./ ver. ν_x/ν_y	11.22/ 3.15
Natural chromaticity hor./ ver. ξ_x/ξ_y	-22.964/ -17.145
Emittance /nm rad ϵ_0	5.982
Loss per turn /keV	114.1
Natural energy spread σ_δ	0.745 $\times 10^{-3}$
Momentum compaction	3.055 $\times 10^{-3}$
β_x/ β_y in the middle of straight /m	5.684/ 2.837

EFFECT OF STRONG INSERTION DEVICES

Strong insertion devices have a non-negligible impact on the beam optics through vertical focusing which results in a vertical tune shift according to formula:

$$\Delta\nu_y \approx \frac{\pi L \langle\beta_y\rangle K^2}{2\lambda_u^2\gamma^2}, \quad (1)$$

where ν_y is the vertical tune, L the length of the undulator, K the ID strength parameter, λ_u the period length and γ the relativistic energy. A strong planar ID inserted in the lattice also generates a vertical beta beat:

$$\frac{\Delta\beta_y}{\beta_y} \approx \frac{2\pi\Delta\nu_y}{\sin(2\pi\nu_y)}. \quad (2)$$

In order to correct for these effects proper optics matching has to be performed and the working point needs to be restored [4]. For the Solaris storage ring lattice the local matching can be done either by installing two extra quadrupole doublets upstream and downstream of the ID or changing locally the gradient of the flanking focusing quadrupoles SQF_o and the gradient in the flanking bending

* Work supported by the European Regional Development Fund within the frame of the Innovative Economy Operational Program:POIG.02.01.00-12-213/09,
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magnets. The second approach can be executed by adding extra power supplies on the flanking SQF_o as well as on the pole face strips of the flanking dipoles.

Superconducting Wiggler

The superconducting wiggler (SCW) that is being considered has 25 periods. The main wiggler parameters are: the nominal peak field of 3.5 T, a period length of 61 mm with a pole gap of 10.2 mm. This type of wiggler is presently used at MAX-lab [5].

In order to study the wiggler's influence on the beam dynamics a simple wiggler model based on a sine-like piecewise representation of the field is elaborated and inserted into the storage ring lattice. Matching to the bare lattice was done by using the OPA code [6]. Insertion of the SCW results in 2.15% vertical tune shift (from 3.15 to 3.218) and large vertical beta beats (in the range of 50%). The beta distortion was recovered locally by increasing the gradient by 0.1% in the flanking focusing quadrupoles and the defocusing gradient in the adjacent bending magnets by 4.5%. This however left some dispersion in the straights. In order to reduce the leak the gradient of the dispersive quadrupoles SQF_i is changed locally by $+0.1\%$ A resulting betatron tune shift was cancelled by reducing gradients globally in dipoles by 0.51% and SQF_o by 0.04% in the ring. The resulting β_y in the middle of the straight is higher (3.158 m) than for the bare lattice. Use of the SCW reduces the bare lattice emittance to 5.279 nm rad. The lattice functions obtained after matching the adjacent DBA cells are shown in Fig. 1.

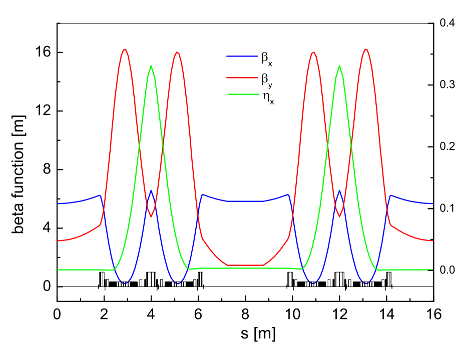

Figure 1: Two achromats with a 3.5 T SCW insterted in between.

Elliptical Undulator

The influence of an APPLE-II type undulator (EPU96) in the planar and vertical polarisation mode on the beam optics with parameters given in Table 2 has also been studied. The performance of EPU96 for all modes: planar, vertical and helical was studied using the radia code and it is presented in [7]. In this work however only simplified models of the undulator available in OPA [6] and elegant [8] were used in order to match the optics.

Table 2: Parameters of the Elliptical Undulator (EPU)

Parameter name	planar	vertical
Undulator Period	96 mm	96 mm
Undulator Gap	13 mm	13 mm
Total Length	2516 mm	2516 mm
Undulator Phase	0.000 mm	48.000 mm
Vertical Peak Field	1.244 T	0.000 T
K	11.611	9.800
Horizontal Peak Field	0.000 T	1.085 T
Emitted Power	1.802 kW	1.284 kW
Photon Energy Harm.1	0.003 keV	0.005 keV

The optics and tunes were restored with the same matching approach as for the SCW described above. To match the lattice optics to the EPU96 in planar mode the dipole and and SQF_o gradients were increased by 3.15% and 0.1%, respectively and global adjustment was applied to the dipole gradient of -0.31% in order to restore the tune. However the resulting β_x and β_y in the middle of the straight are higher by 0.42% and 5.5%, respectively. The vertical mode of EPU operation requires decreasing of flanking SQF_o gradient by 3.1% as well as increasing of the flanking dipoles' and SQF_i gradients by 2.25% and 0.1%, respectively. To obtain the correct tunes a global adjustment in the range of -0.28% to the dipole gradient was applied. The EPU96 reduces the emittance by 3% with respect to the bare lattice emittance and increases the synchrotron radiation losses per turn by 4.6%. The matched betatron functions for EPU96 in vertical mode are shown in Fig. 2.

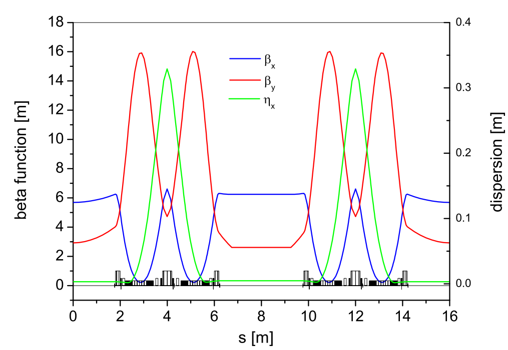

Figure 2: Two achromats with a 3.5 T SCW installed in between.

EFFECT ON NONLINEAR OPTICS

Although the linear optics can be restored quite well, an investigation of the nonlinearbeam dynamics is also required. The bare lattice chromaticity was corrected to $+1$ by using chromatic sextupoles. It was noticed that the studied IDs have only a small effect on the chromaticity after proper matching. In the case of the SCW the natural

ISBN 978-3-95450-115-1

chromaticity is $\xi_x = -22.972$ and $\xi_y = -17.502$, whereas for EPU96 in planar mode the values are: $\xi_x = -22.989$ and $\xi_y = -17.353$. Because of the small deviation, the chromaticity correction was left unchanged. The chromatic tune shifts (CTSs) were calculated for the SCW and EPU96 in a planar mode by using the OPA code [6]. The results for the EPU96 are presented in the Fig. 3. Additionally, amplitude dependent tune shifts (ADTS) were calculated for both cases and the results are plotted in Figs. 4 and 5.

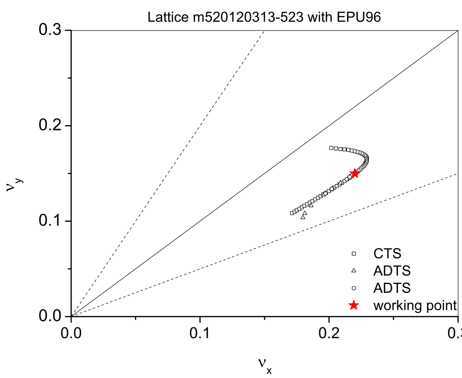

Figure 3: A plot of the fractional tune space when using an EPU96.

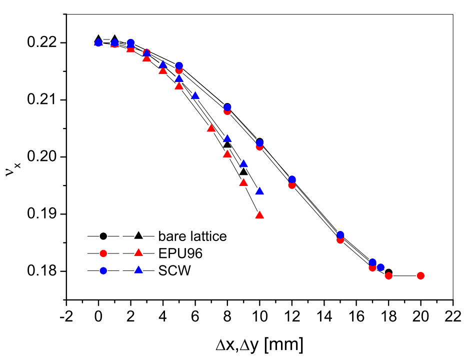

Figure 4: The amplitude-dependent horizontal tune shift for the lattice with EPU96 or SCW compared with bare lattice. The circles indicate horizontal excursions, the triangles indicate vertical excursions.

Since the deviations in the chromaticity and ADTS are small, the tune footprint of the lattice with one SCW and one EPU96 without modification in the sextupole settings remains very similar to the original bare lattice footprint. As a result, also the dynamic aperture (DA) with one SCW is fairly similar to the bare lattice DA [2]. It appears sufficient to match the linear optics to the SCW. The sextupoles settings can be left unchanged. OPA tracking performed for the lattice with EPU96 has shown sufficient DA for on and off-momentum particles, however, 6D tracking is needed to verify these results. This is on-going work and will be presented elsewhere.

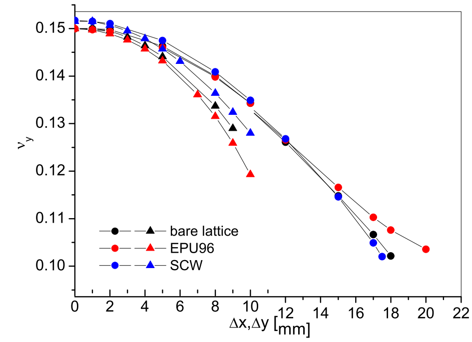

Figure 5: The amplitude-dependent vertical tune shift for lattice with EPU96 or SCW compared with bare lattice. The circles indicate horizontal excursions, the triangles indicate vertical excursions.

CONCLUSIONS

The presented studies support the requirements on the achromat magnet design. It has been shown that in order to have the possibility to match the Solaris lattice optics to strong IDs a tuning range of 4.5-5% has to be provided both for SQF_o and for pole-face strips on dipoles. This could be demanding. Alternatively, an different matching procedure has to be attempted. One possibility is to add extra doublets of quadrupole either side of the ID. This however has several disadvantages. One is that extra space is required for the additional quadrupoles and, as was shown for the SCW, matched optics result in an increase of the horizontal beta function in the middle of the ID of 65%.

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