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LATTICE OPTIONS WITH REVERSE BENDING MAGNETS FOR USSR HMBA STORAGE RING

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Abstract

The 4th generation light source, the Ultimate Source of Synchrotron Radiation (USSR4) is under design, to be built in Moscow region (Russia). It will be a 6 GeV and about 1100 m circumference storage ring synchrotron [1-3]. Baseline lattice of the USSR4 for now is a scaled version of the ESRF-EBS Hybrid Multi-Bend Achromat (HMBA) lattice that was successfully commissioned in 2020 [4-7]. Its natural horizontal electron beam emittance is about 70 pm·rad. Further reduction of beam emittance can be achieved with the use of reverse bending magnets. The evolution of the envisaged lattices for the USSR4 storage ring, including options with reverse bends is presented.

INTRODUCTION

Today third- and fourth-generation synchrotron radiation (SR) sources and X-ray free-electron lasers (FEL's) have many different applications in materials science, molecular biology and biochemistry, biomedical studies, crystallography, spectroscopy, studies of fast processes and other fields of scientific and applied research. For such applications the main problem is reaching the diffraction limit for a given beam energy of 3-6 GeV: thereby, an object can be imaged with high contrast and sharpness once its size is comparable to the wavelength of the synchrotron or undulator radiation. It was assumed that transverse emittance value below 100 pm·rad is necessary for the fourth generation light source to reach new horizons in the research by using SR. For a long time it was assumed that such values of the emittance could be reached only with FEL's driven by high-brightness electron linacs. A few years ago, it was demonstrated that low horizontal emittances can be achieved in storage synchrotrons as well and first beams with emittances about 100 pm·rad were generated at MAX-IV (Sweden) [8] and ESRF-EBS (France) [7] synchrotron light sources. Several similar facilities are under design and construction stages [9, 10] but today's trend is the existing SR sources upgrade to the fourth generation.

It is proposed that USSR4 facility will include both the 6 GeV storage synchrotron and FEL(s). The choice of this layout leads to the complication of injection system based on the full-energy linear accelerator. This linac will be used both for top-up injection into storage ring and for a generation of the high-brightness drive bunches for FEL.

SYNCHROTRON RING LATTICE

Baseline lattice of the USSR4 for now is a scaled version of the ESRF-EBS 40-fold symmetry HMBA lattice that consists of 7 bends for each cell, 4 of them being the so-called LGB magnets, 2 are combined-function magnets (DQ) and "triplet of the magnets" at the centers of the 38 standard cells (Fig. 1). The main difference of this lattice from ESRF-EBS one is the presence of 5 cm long short bend (SB) with high field (~0.86 T) at the cell center. This lattice ensures the designed horizontal emittance 70 pm·rad together with Touschek lifetime (TLT) is equal to 28.9 h for zero current approximation, momentum acceptance (MA) is equal to ±6% at the center of the straight section and sufficient off-momentum dynamic aperture (DA) for off-axis injection schemes (± 1 cm in horizontal plane and about 3 mm in the vertical one) [2]. An advantage of that lattice is the scaling of the commissioned ESRF-EBS storage ring synchrotron and needs minimal changes of components (magnets, chambers) to start its construction in a short time.

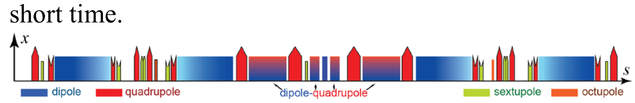

Figure 1: Layout of baseline lattice.

However, equilibrium electron beam horizontal emittance ε_x already now in 1.5-2 times lower than 70 pm for the similar projects [9, 10] in view of energy and circumference of SR sources. It is well known that the next step towards lower ε_x values is anti-bends (reverse bends) implementation [11-13] together with mentioned LGB magnets under constant beam energy. So, the expected ε_x value is about 45 pm for 1104 m long 6 GeV APS-U project [10]. The APS-U lattice is the scaled and modified ESRF-EBS HMBA lattice with six reverse bend (RB) gradient dipoles.

Firstly, an attempt was made by authors to re-optimize USSR baseline lattice by means of re-tune magnets parameters to reduce ε_x value up to 50 pm. The problem could not be solved without significant modification of the baseline lattice or RB introduction.

The next step toward the solution of the mentioned problem was the considering of RB introducing into baseline lattice by corresponding shifts of the existing quadrupoles in the horizontal plane from the closed orbit. An example of USSR4 lattice with reverse bends is presented in Fig. 2 (we considered lattice without SB at the cell center and with one DQ there).

The main tasks for the lattice optimization were:

1. ε_x value is about 50 pm or lower.

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2. Zero dispersion at centres of straight sections.
3. Realization of "–I transformation" conditions.
4. Acceptable DA value for off-axis injection.
5. MA and TLT comparable with that are for baseline lattice or bigger.
6. Fields of magnets should not exceed the upper limits designed for ESRF-EBS magnets.

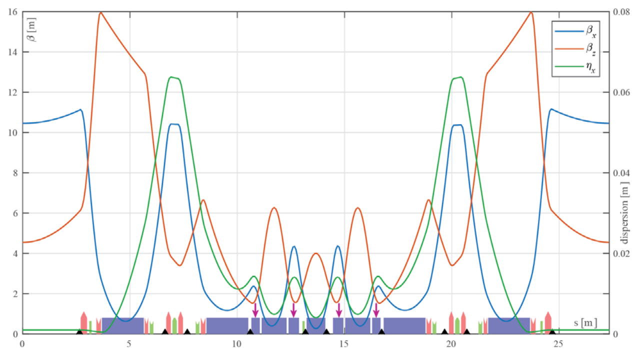

Figure 2: Layout of considered lattice with RB.

Lattice optimization was carried out by means of MADX [14], AT [15], Pyhton [16]. With the help of Nelder-Mead simplex method [17] it was obtained a set of ε_x values for different absolute value of the bending angle ψ of reverse bend that is presented in Fig. 3. Note that the fields of LGB magnets was changed too. A dependence of horizontal partition number J_x [18] on ψ values is shown in Fig. 4. From this figures one can find that ε_x value lower than 50 pm corresponds for $|\psi|$ values greater than 2 mrad and, consequently, J_x values closed to 2. Typical distribution of fields of dipoles along the cell, for instance for the lattice with $\varepsilon_x = 50$ pm, shown in Fig. 5. DA for that lattice is shown in Fig. 6. It follows that DA sizes in the horizontal and vertical plane are about ±3 mm and 3 mm that is still not enough for off-axis injection. Note, that DA sizes for APS-U project with swap-out injection in the horizontal and vertical plane is about ±3 mm and 3 mm correspondingly.

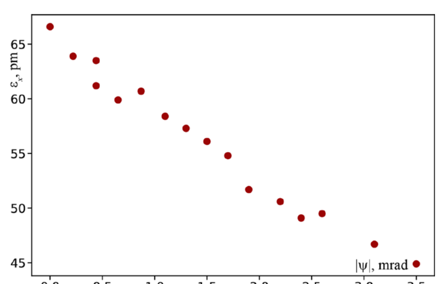

Figure 3: Dependence of ε_x on $|\psi|$.

The supposition that was made during RB introducing into baseline lattice is vacuum chamber geometry the same as for ESRF-EBS one. It is clear that RB can change beam orbit so that vacuum chamber geometry will need to be redesigned and, consequently, to perform gas loads and impedance calculations, beam instabilities investigation and so on. The required shifts of RB gradient dipoles can be estimated by means of following expression

$$|\psi_{\mathrm{RB}}| = |k_1 l \Delta x|, \qquad (1)$$

where k_1 is the the quadrupole strength, l is its length, Δx is its horizontal shift.

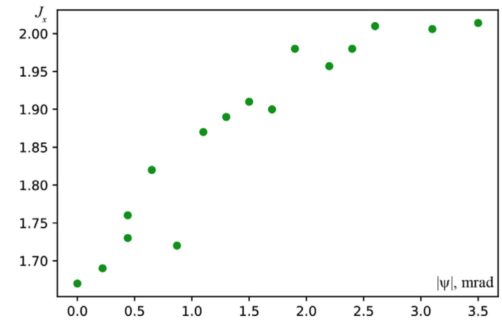

Figure 4: Dependence of J_x on $|\psi|$.

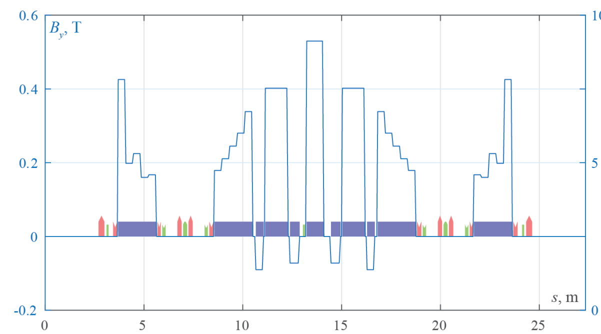

Figure 5: Typical distribution of dipoles fields.

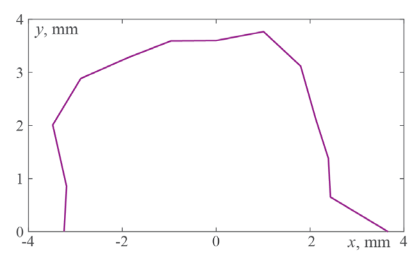

Figure 6: Example of DA for the lattice option with RB.

A graph of a dependence of absolute value of closed orbit shift on absolute value of shift of RB gradient dipole is presented in Fig. 7. It follows that possible Δx value is lower than 0.7 mm because of horizontal dimension of vacuum chamber cross section. That dimension is supposed to be equal to 16.5 mm for the cell central region. In turn, this means that $|\psi|$ value is less than 1.2 mrad and, in accordance with Fig. 3, ε_x is greater than 60 pm.

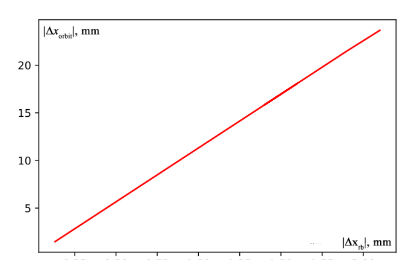

Figure 7: Dependence of absolute value of closed orbit shift on absolute value of RB shift.

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CONCLUSION

The evolution of the envisaged lattices for the USSR storage ring, including options with reverse bends is presented. It is pointed that it is not possible to reduce equilibrium horizontal beam emittance down to 50 pm by means of reverse bend gradient dipoles implementation under condition that vacuum chambers should be the same as for ESRF-EBS main ring. Nevertheless, reverse bends allow one to reach equilibrium horizontal emittance lower than 50 pm·rad, but it will need to redesign significant amount of the magnets, vacuum chambers, etc.

REFERENCES

[1] I. A. Ashanin *et al.*, "Conceptual design of a dedicated fourth-generation Specialized Synchrotron radiation Source (SSRS-4) at the Kurchatov Institute", *Phys. Atom. Nuclei*, vol. 81, no. 11, pp. 1646-1651, 2018. doi:10.1134/S1063778818110030

[2] S.M. Liuzzo *et al.*, "USSR HMBA Storage Ring Lattice Options", presented at IPAC'21, Campinas, Brazil, May. 2021, paper TUPAB049, unpublished.

[3] T.V. Kulevoy *et al.*, "USSR - the Project of the Ultimate Synchrotron Radiation Source in Russia", presented at IPAC'21, Campinas, Brazil, May 2021, paper TUPAB055, unpublished.

[4] "EBS Storage Ring Technical Report", ESRF, Grenoble, France, 2019. https://www.esrf.eu/files/live/sites/www/files/about/upgrade/documentation/Design%20Report-reduced-jan19.pdf

[5] S.M. Liuzzo *et al.*, "Preparation of the EBS beam commissioning", *J. Phys.: Conf. Ser.*, vol. 1350, p. 012022, 2019. doi:10.1088/1742-6596/1350/1/012022

[6] S.M. Liuzzo *et al.*, "Hybrid multi bend achromat at 3 GeV for future 4th generation light sources", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2822-2825. doi:10.18429/JACoW-IPAC2016-WEPOW006

[7] S. White *et al.*, "Commissioning and restart of ESRF-EBS", presented at IPAC'21, Campinas, Brazil, May 2021, paper MOXA01, unpublished.

[8] "MAX IV Facility Detailed Design Report", Lund, Sweden, Aug. 2010. https://www.maxiv.lu.se/accelerators-beamlines/accelerators/accelerator-documentation/max-iv-ddr

[9] G. Xu, X.H. Cui, Z. Duan, Y.Y. Guo, "Progress of the lattice design and physics studies on the high energy photon source", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 2697-2699. doi:10.18429/JACoW-IPAC2019-TUPGW046

[10] R.O. Hettel, "Status of the APS-U Project", presented at IPAC'21, Campinas, Brazil, May 2021, paper MOXA02, unpublished.

[11] J.-P. Delahaye and J.P. Potier, "Reverse bending magnets in combined function lattice for the CLIC damping ring", in *Proc. PAC'89*, Chicago, Illinois, March 1989, pp. 1611-1613. doi:10.1109/PAC.1989.72869

[12] A. Streun, "Use of reverse bending magnets in multi-bend achromat lattices", presented at IPAC'20, Caen, France, May 2020, paper WEVIR01, unpublished.

[13] A. Streun, "The anti-bend cell for ultralow emittance storage ring lattices", *Nucl. Instrum. Methods in Phys. Research A*, vol. 737, pp. 148-154, 2014. doi:10.1016/j.nima.2013.11.064

[14] L. Deniau, H. Grote, G. Roy, *The MAD-X Program User's Reference Manual Version 5.03.07*. http://cern.ch/madx/releases/last-rel/madxuguide.pdf

[15] W. Rogers *et al.*, "pyAT: A Python build of Accelerator Toolbox". in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3855-3857. doi:10.18429/JACoW-IPAC2017-THPAB060

[16] G.V. Rossum and F.L. Drake, *Python 3 Reference Manual*, CreateSpace, Scotts Valley, CA, USA, March 2009.

[17] J. Nelder and R. Mead, "A simplex method for function minimization", *Comput. J.*, vol. 7, pp. 308-313, 1965. doi:10.1093/COMJNL/7.4.308

[18] M. Conte and W.W. MacKay, *An introduction to the physics of particle accelerators*. Singapore: World Scientific Publishing, 2008.