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NEW LATTICE DESIGN FOR KURCHATOV SYNCHROTRON RADIATION SOURCE

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Abstract

Nowadays the upgrade project of the 2nd generation synchrotron radiation source operating at NRC "Kurchatov Institute" has been ongoing. The main aim of the project is to create a new synchrotron radiation source with the same 124 m circumference and providing synchrotron radiation properties inherent to the 3rd generation sources (emittance ~3 nm·rad). The new machine will consist of a new storage ring with 2.5 GeV electron energy, full energy booster synchrotron, and 0.2 GeV linac. The mandatory requirement for the project is to keep all currently operating beamlines.

In this article, we present the design challenges and approaches for this machine, the conceptual design, and the baseline lattice.

INTRODUCTION

Kurchatov synchrotron radiation source is a 2nd generation source with 2.5 GeV electron beam energy and 98 nm·rad emittance. The circumference of the main storage ring is 124.13 m. The main storage ring lattice is based on a modified DBA type lattice and consists of 6 cells, each of which contains two 3 m straight sections [1].

Currently, 13 beamlines operate regularly and 4 more are under construction. The main source of synchrotron radiation is bending magnets with 1.7 T magnetic fields. The characteristic photon energy is 7 keV and the full spectral range of synchrotron radiation is 0.1 – 2000 Å. To expand the facility's experimental opportunities 3 superconductive wiggles were installed in the straight sections of the main storage ring (one with 7.5 T and two with 3 T maximum fields).

Improving qualities of photon beams primarily associated with an increase in their intensity and brightness requires the upgrade of the facility completely. So, after such upgrade, the facility must have an electron beam emittance less than 5 nm·rad and provide synchrotron radiation beams with properties close to properties of the beams generated by the 3rd generation sources. For this apart from the development of a new main storage ring, it is necessary to develop a new full energy booster synchrotron and a new linac. Moreover, a mandatory requirement for the upgrade project is the preservation of all currently operating beamlines.

MAIN REQUIREMENTS

DBA type lattice was designed in the mid-1970s by R. Chasman and G. Green and formed the basis of the 2nd and 3rd generation synchrotron radiation sources [2]. The development of technologies for creating magnet, RF, vacuum systems, software, and hardware for 3D simulations have created opportunities for the construction of new synchrotron radiation sources based on MBA lattice. The use of complex and high-precision magnet elements in MBA lattice makes it possible to reduce electron beam emittance up to 2 orders and even more than in DBA lattice. While the circumferences of both storage rings are about the same. The first successfully commissioned such projects are MAX-IV [3] and ESRF upgrade project – ESRF EBS [4]. Also, deserve attention projects such as the SLS-2 project [5] and one of the most ambitious to date – the PETRA-IV project [6].

Based on the last progress in accelerator physics and technologies and on world scientific community experience in an upgrade of working synchrotron radiation sources we have formulated the main requirements for the new Kurchatov synchrotron radiation lattice:

- Preservation all currently operated beamlines.
- Achievement the electron beam emittance less than 5 nm·rad.
- Preservation spectral range of synchrotron radiation.
- Preservation ring symmetry and zero-dispersion straight sections.
- Providing the possibility of electron beam injection and storing.
- Beam lifetime more than 10 hours.
- Preservation of the main storage ring circumference.
- Compliance with technological limitations.

NEW LATTICE

Kurchatov synchrotron radiation source is one of the compact sources in the world. The small circumference of the main storage ring is achieved through the use of bending magnets with a high magnetic field (1.7 T). This imposes very strict limitations from the technologies side.

To reduce electron beam emittance and simultaneously minimize a storage ring circumference, it is advisable to use special magnets with combined functions (like sandwich type magnets) and antibend magnets [7, 8]. Based on the results of the conducted research the modified 3BA type lattice is optimal for the new Kurchatov synchrotron radiation source. This half of lattice formed from 3 bending magnets with 2.0 T magnetic field, 4 combined functions magnets, 4 magnets with antibend, 2 doublets of quadrupole lenses, 6 chromatic and 1 harmonic sexupoles. In the new lattice, there are no octupoles. A comparison of current and new lattices of the Kurchatov synchrotron radiation source is illustrated in Fig. 1.

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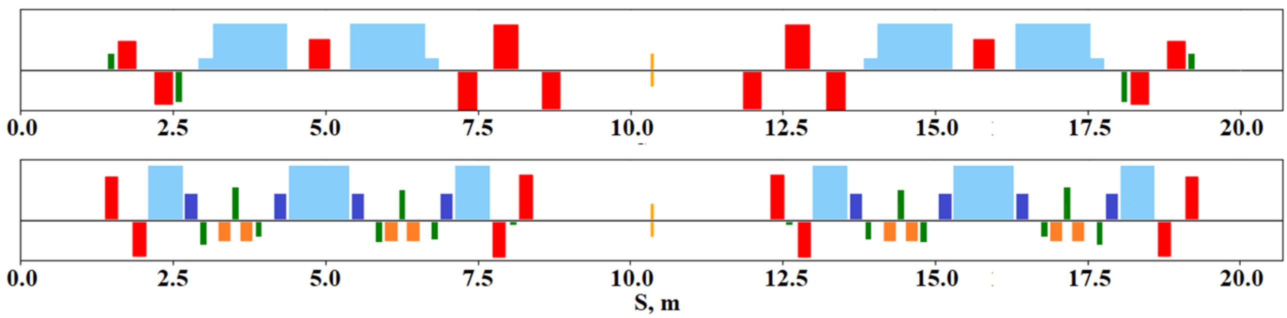

Figure 1: A comparison of current (top) and new (bottom) lattices of the Kurchatov synchrotron radiation source. Light blue – main bending magnets with 2 T magnetic field, blue – special magnets with combined functions, orange – antibend magnets, red – quadrupoles, green – sextupoles.

To reduce electron beam emittance as much as possible in the new lattice a few requirements above was dropped. Namely circumference of the main storage ring and the position of straight sections are not saved exactly. Since the fulfillment of these requirements does not allow obtaining the emittance of the electron beam less than 10 nm·rad. In addition, to increase the space between magnetic elements, the field in bending magnets was increased from 1.7 to 2.0 T. Avoiding strict compliance with these requirements is a compromise between achieving a low emittance and technical difficulties of a new project.

Optics functions of the new lattice are illustrated in Fig. 2.

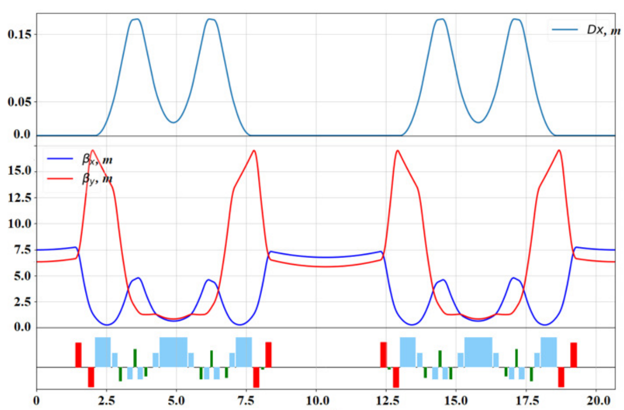

Figure 2: Optics functions.

A distinctive feature of the new lattice is the increased length of the straight section with zero dispersion in the current lattice. This will make it possible to install longer insertion devices into it. The second straight section in the new lattice has also zero dispersion and can be used for insertion devices installation too. As well horizontal and vertical betafunctions in the straight section are approximately the same. This will allow to tune machine to operate in special mode with round beams of synchrotron radiation from insertion devices. All of this will expand the facility's performance.

Achieving low emittances requires lattices with more strong quadrupoles, which leads to an increase in natural chromaticity and to an increase in the strengths of sextupoles used to compensate for it. This leads to a stronger nonlinear motion of electrons, the appearance of a large number of resonances, and a decrease in the size of the dynamic aperture. To compensate for natural chromaticity, increase the size of the dynamic aperture and minimize the betatron tunes shifts 6 chromatic and 1 harmonic sextupole families are used. The strengths of sextupoles have been optimized with the help of genetic algorithms enhanced by machine learning [9] to minimize nonlinear effects on the electron beam dynamics.

The dynamic aperture in the middle of the injection straight section is presented in Fig. 3. The vertical size of the dynamic aperture without any errors is ±12 mm and horizontal size – ±16 mm. This dynamic aperture size is sufficient to inject an electron beam using an off-axis injection scheme with 4 kickers.

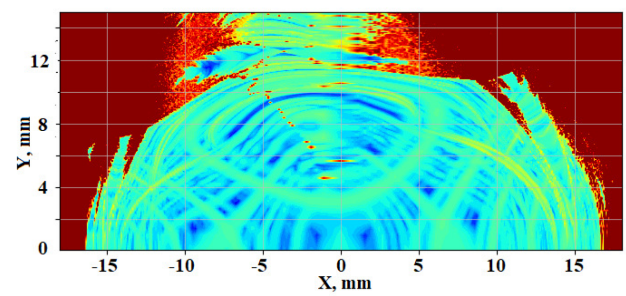

Figure 3: The dynamic aperture in the middle of the injection straight section.

A tune diagram for the good field region (±11 mm in horizontal and ±8 mm in vertical planes) is shown in Fig. 4. The working point was removed from low-order resonances at a sufficient distance to ensure stable betatron oscillations with an amplitude of up to 10-15 mm and an energy spread of up to 3.5 %.

The projected parameters of the new Kurchatov synchrotron radiation source are summarized in Table 1.

The influence of errors on the dynamic aperture is shown in the Fig. 5, closed orbit in Fig. 6 and Fig. 7. Here all elements have errors in a magnetic field, gradient, horizontal and vertical displacement, and tilt.

After the correction dynamic aperture restores almost to the reference aperture without errors. A similar situation with compensation for closed orbit distortion. After correction, residual distortions do not exceed 20 μm in both planes.

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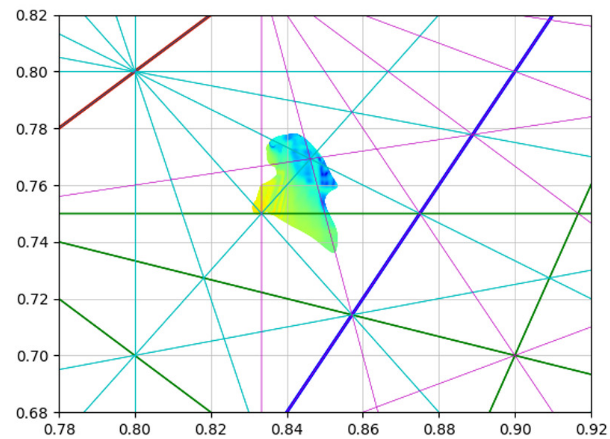

Figure 4: Tune diagram.

Table 1: Main Parameters

Parameter	Value
Energy	2.5 GeV
Circumference	124.169 m
Emittance	2.86 nm·rad
Beam current	up to 200 mA
Tunes	14.8529 / 6.7551
Chromaticity	-29.3 / - 27.1
Energy loss	925.4 keV
Dumping times	0.955/2.238/3.404 ms
RF frequency	181.078 MHz

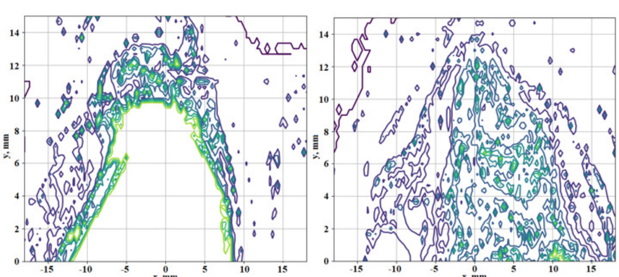

Figure 5: Dynamic aperture with errors. $\sigma_{x/y}$ is 35 μm on the left and 100 μm on the right.

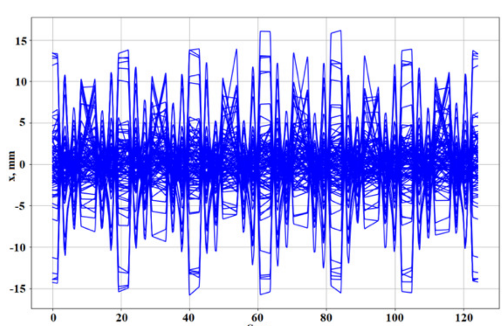

Figure 6: Horizontal orbit distortions, $\sigma_{x/y}$ is 50 μm.

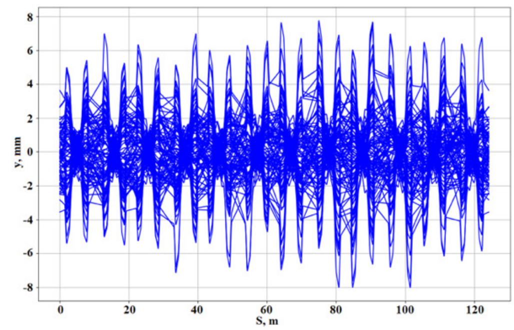

Figure 7: Vertical orbit distortions, $\sigma_{x/y}$ is 50 μm

SUMMARY AND OUTLOOK

Design study for the Kurchatov synchrotron radiation source upgrade is ongoing and a reference lattice is in place. Projected baseline parameters are 200 mA current, 2.86 nm·rad emittance. Tolerance studies and commissioning simulations are ongoing, R&D on technical subsystems has been launched. Despite all the difficulties the project looks quite real from a technical point of view.

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