SHORT BUNCH OPERATION MODE DEVELOPMENT AT THE SYNCHROTRON RADIATION SOURCE SIBERIA-2*

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Abstract

Decrease of the electron bunch length gives rise to coherent synchrotron radiation in the THz spectral region. Also, the short photons pulse could provide an option for time-resolved processes studies. Currently the possibility to operate with short electron bunch of the synchrotron radiation source Siberia-2 is under consideration for this purpose. In the report the techniques of electron bunch shortening are described as well as the requirements are given for the electron bunch and lattice parameters. The authors present a modified lattice for the synchrotron radiation source Siberia-2 with low momentum compaction factor and the results of the beam dynamics studies.

INTRODUCTION

Kurchatov synchrotron radiation source consists of LINAC (pre-injector) with electron energy of 80 MeV, booster Siberia-1 (synchrotron radiation source in the VUV and soft X-ray spectrum) with electron energy of 450 MeV and main storage ring Siberia-2 with electron energy of 2.5 GeV. Main parameters of Siberia-2 storage ring are presented in Table 1.

Table 1: Siberia-2 Storage Ring Main Parameters into Regular User Operation Mode

Parameter	Value
Circumference	124 m
Beam energy	2.5 Gev
Beam current	up to 150 mA
Number of bunches	1 – 75
Horizontal emittance	98 nm·rad
Horizontal/vertical tune	7.775 / 6.695
Linear momentum compaction factor	$10 \cdot 10^{-3}$
Horizontal/vertical chromaticity	-16.9 / -12.9

Siberia-2 magnetic lattice consists of 6 mirror symmetric cells with 4 bending magnets and 6 quadrupole lenses. Each cell contains one nondispersive straight section (3 m) for installing RF cavities and insertion devices and one dispersive straight section (3 m). The chromaticity is correcting by 2 families of sextupole lenses. Optical functions of one of Siberia-2 superperiods which used now in work on synchrotron radiation experiments are shown in Fig. 1.

Siberia-2 is working at 2.5 GeV electron beam energy and with 98 nm·rad horizontal emittance in the regular operation mode for users. Also, the facility has an extended regular mode with super conductive wiggler operation.
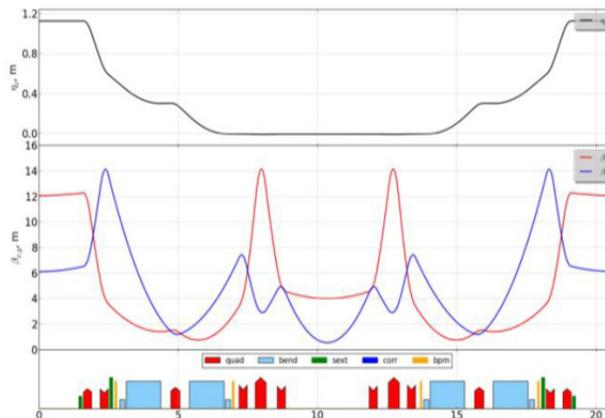

Figure 1: Optical functions for regular user operation mode of one out of 6 ring cells.

To extend the capabilities of the facility and to provide for time-resolved process studies we started developing the low-alpha operation mode for Kurchatov synchrotron radiation source. We focused on study optimization methods, e.g. genetic and Nelder-Mead Simplex, and its application for optics design. As the result, low-alpha lattice was developed as well as a dynamics aperture study of the lattice was performed.

DESCRIPTION OF OPTIMIZATION METHOD

We set following requirements and restrictions before designing the low-alpha lattice. To keep good injection efficiency into the Siberia-2 storage ring new optics must have a large dynamic aperture. Besides, of course, the beam emittance should not be more than that in the regular user operation mode. Switching from the regular operation mode to low-alpha mode should be performed only by adjusting the quadrupole lenses strengths. As previously the six-fold symmetry optics is required for the low-alpha mode.

To find new low-alpha lattice we used the Multi-Objective Genetic Algorithm which was specifically implemented as machine optics optimization module for Ocelot framework [1] used for a beam dynamics study.

The aim of our multi-objective optimization problem was to find all possible tradeoffs among multiple objective functions that are usually conflicting. Beam

emittance and momentum compaction factor were used as objective functions and the strengths of 6 quadrupole lens were used as variables.

The block diagram of Multi-Objective Genetic Algorithm used is shown in Fig. 2. This block diagram is common for optimization using genetic algorithms. For our optimization problem Step 2 (selection) and Step 5 (elitist strategy) are of particular interest.

Step 0: Initialization

Step 1: Evaluation

Step 2: Selection

Step 3: Crossover   Step 5: Elitist strategy

Step 4: Mutation

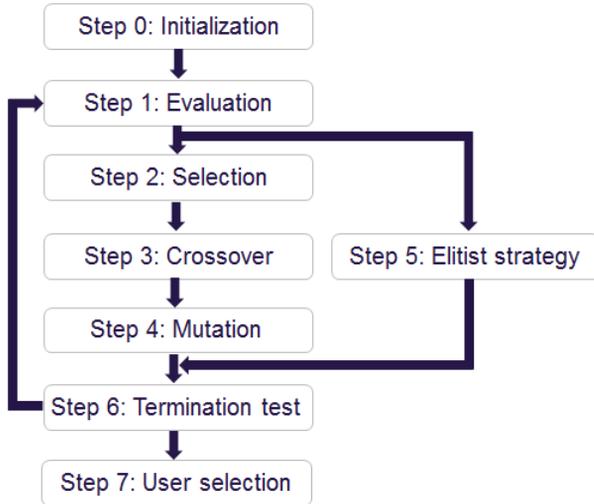Step 6: Termination test

Step 7: User selection

Figure 2: The block diagram of the Multi-Objective Genetic Algorithm.

The Nondominated Sorting Genetic Algorithm II [2] is used for selection. As well we tried to use simpler and faster Random Weights Genetic Algorithm [3] for selection, but it gave worse results as compared with the first one for our emittance-alpha optimization problem.

When you optimizing a problem with using smooth and continuous fitness function the genetic algorithms help and everything works well. But when solving a optimization problem for circular accelerators with use the genetic algorithms a trouble arises, namely, due to not smooth and not continuous fitness function. As consequence in the case of circular accelerator there are a lot of not periodic or incorrect solutions. As a result optimization will not be done.

To solve this problem the elitist strategy is used. During every new generation after fitness functions evaluation a certain number of best solutions are selected as elite individuals. When mutation is done N solutions are randomly removed from the current population and replaced by solutions from elite individuals. This elite preserve strategy has an effect in keeping the variety of each population.

Since it is difficult to choose a single solution for a multi-objective optimization problem without iterative interaction with the decision maker, one general approach is to show the set of Pareto optimal solutions to the decision maker. Then one of the Pareto optimal solutions can be chosen depending on the preference.

Pareto frontier and Pareto optimal solutions during emittance-alpha optimization is shown in Fig. 3. Blue

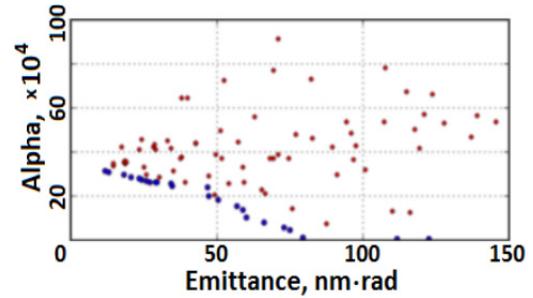dots – Pareto optimal (nondominated) solutions, red dots – other (dominated or not Pareto optimal) solutions.

Figure 3: Pareto frontier. Blue dots – Pareto optimal solutions, red dots – other solutions.

THE RESULTS

After emittance-alpha optimization we have that minimum emittance is approximately 80 nm·rad when it is possible to reduce momentum compaction factor at least 30 times as compared with regular optics. For the Siberia-2 magnetic lattice, as for any circular accelerators, we have the smaller emittance, the greater chromaticity and, accordingly, a dynamic aperture decreasing. Because of that we decided to keep the beam emittance approximately the same as in the regular operation mode (98 nm·rad) and to reduce the momentum compaction factor as much as possible.
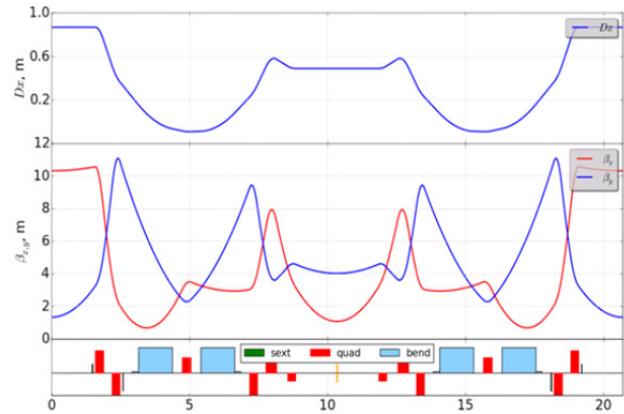

Figure 4: Optical functions for low-alpha operation mode of one out of 6 ring cells.

For final lattice fine-tune the Nelder-Mead Simplex method was used. The result of optimization is presented in Fig. 4 – optical functions for low-alpha operation mode of one out of 6 ring cells. After successful optimization the linear momentum compaction factor is reduced more then 10^4 times and emittace is kept approximately the same. The main parameters of the Siberia-2 storage ring into low-alpha operation mode are presented in Table 2.

To reduce momentum compaction factor the optics should provides a changing of dispersion function sign inside the bending magnets. These leads to the fact that it is impossible to set zero dispersion function into all straight sections. So into this low-alpha mode operation with superconductive wiggler will be not recommended.

Table 2: Siberia-2 Storage Ring Main Parameters into Low-Alpha Operation Mode

Parameter	Value
Horizontal emittance	94 nm·rad
Horizontal/vertical tune	8.567 / 5.306
Linear momentum compaction factor	$6 \cdot 10^{-6}$
Horizontal/vertical chromaticity	-13 / -10

To control the transverse chromaticity and dynamic aperture the low-alpha optics requires tuned sextupole corrections. The natural horizontal and vertical chromaticity into this optics are compared with that of regular operation optics. Horizontal and vertical beta functions have well-spaced in the place of sextupole lenses locations and dispersion has not zero values at these points. All this allows using weak sextupole lens strengths and the large dynamic aperture is expected.
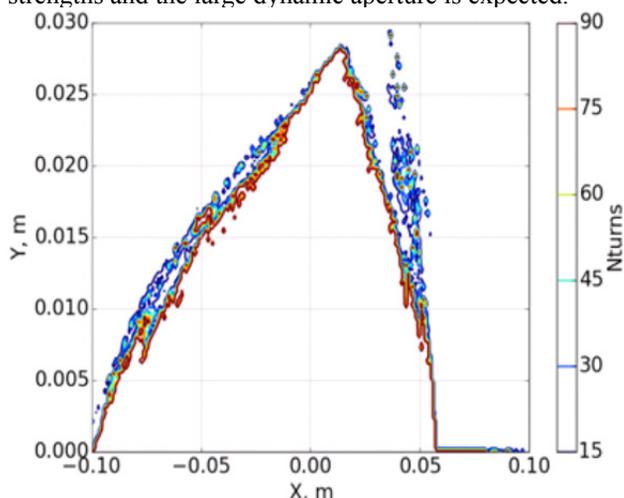

Figure 5: The dynamic aperture for low-alpha optics.

On the Fig. 5 the dynamic aperture for low-alpha machine optics is shown. The dynamic aperture obtained during nonlinear beam dynamics simulation is slightly lager one into regular user operation optics.

CONCLUSION

The low-alpha optics has been found for the Kurchatov synchrotron radiation source. The developing and commissioning new operation mode will allow us to extend experimental opportunities of the facility.

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