SUPER BRIGHT LATTICE FOR THE IRANIAN LIGHT SOURCE FACILITY STORAGE RING

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Abstract

To have a competitive leading position in the future and to obtain ultra low beam emittance, save energy and minimizing operation cost, we have designed lattice based on the 5 low field dipole magnets per cell for the storage ring of Iranian light Source Facility (ILSF). The designed lattice has the capability of both soft and hard x-ray radiation from central dipoles. In this paper, we give specifications of lattice linear and nonlinear optimization and review properties of the radiated x-ray.

INTRODUCTION

The ILSF project is the first Iranian synchrotron radiation source which will be built in the city of Qazvin located 150 km West of Tehran. Based on the ILSF strategy, various requirements of the modern synchrotron radiation sources cannot be totally fulfilled at this facility but it will provide super bright synchrotron radiation required for the cutting-edge science in several fields and will serve as a significant impetus for multidisciplinary research.

Design of the ILSF storage ring was commenced in June 2010. With regarding to the proposed budget and users requirements, several types of lattice with different configurations of the magnets have been explored for the storage ring [1]-[2]. The lattice design study revealed that use of the low field magnets in comparison with the high field one for the ILSF accelerators would be beneficial in several points of views. Although the radiated photon beam critical energy from the low field dipoles limits to a small value which is absolutely useful for the several experiments in the soft x-ray region but the obtained ultra low beam emittance and the small beam spot size with the low field lattice motivated us for further fine optimization of the low field lattice. It has been found that the required high energy hard x-ray photon beam radiated from dipole can be available even with the low field lattice. Lower required RF power, less needed power supply and cooling systems are the other benefits of the using low field magnets which all results to save energy and minimize operation cost. Moreover, the availability of the low field material for the magnets inside Iran results to reduce fabrication cost of them [3]. Construction of the magnets prototypes inside ILSF with Iranian industries revealed that the available ST14 material for the magnets saturates at 1.6 T [3] and it means the upper field limits at pole tip of the quadrupole and the sextupole are 0.8 T and 0.4 T respectively. However, strong quadrupole and sextupole magnets are required to design the ultra low beam emittance lattice and to ease solution of the nonlinear problems respectively. Therefore, the quadrupole and sextupole magnets are designed with small apertures to provide highest field strength. It causes a big impact on the vacuum system design. Moreover the designed lattice does not become very sensitive to the errors of the magnets. Because of the small aperture of the low field magnets and as a consequence for the beam, a low emittance booster is designed to place at the same tunnel as storage ring to assure an efficient injection process and help to reduce construction costs.

Based on the different configurations of the dipoles in a cell, several low field lattice alternatives have been explored for the ILSF ring. As the final solution, we designed lattice with multi dipole per cell for the ILSF ring. It provides an ultra low beam emittance and long enough straight sections which are the main concerns from user's point of view.

LATTICE DESIGN

Several intensive efforts have been performed in the design of third generation synchrotron light sources around the world to meet the future demands of the users for having super bright radiation from ultra low beam emittance. The beam emittance is defined by the structure of magnets in the lattice. It is proportional directly to the square of the beam energy and inversely to the third power of the number of dipoles in the ring as

$$\varepsilon = \mathrm{A}\mathrm{E}^2\mathrm{N}_\mathrm{d}^{-3}, \tag{1}$$

where E is the nominal energy of beam, N_d is the total number of the bending magnets, and constant coefficient A is given by the lattice functions. Proper minimization of the constant A by the suitable choice of the optical functions is named Theoretical Minimum Emittance (TME) approach [4] which usually makes difficult nonlinear problems and causes more sensitivity of the lattice to errors. To design lattice for the 3 GeV ILSF ring, we used large number of the dipoles to strongly reduce the beam emittance. Moreover, to avoid large storage ring circumference and to have large number of beamlines, the designed lattice is optimized to be as compact as possible.

The designed ILSF storage ring is composed of 20 cells and provides 20 straight sections with length of 5.11 m. One of them will be occupied with the injection equipment, two of them are reserved for the RF cavities; the rest straight sections are considered for installation of the insertion devices with the length up to 4 m. Each super period includes of five pure dipoles which each has the field of 0.75 T, length of 0.84 m and bends the beam 3.60 Deg. No any gradient in the dipoles results to lower fabrication cost of dipoles with inside industries and eases alignment of them in the ring. However, focusing in horizontal direction is performed with the use of 10 quadrupoles within 5 families and 6 quadrupoles within 3 families are used for the vertical focusing per cell. General layout of a quadrant of the storage ring is shown in Fig. 1. As depicted, radius of the ring is about 84 m. Mechanical drawing of one super period of the ring lattice is depicted in Fig. 2. Minimum effective length of drift space between the magnets is 18.50 cm which allows comfortable positioning of the magnets and diagnostic systems. Four pumping stations are utilized in the components to provide ultra low vacuum pressure. They are after the two dipoles per cell.

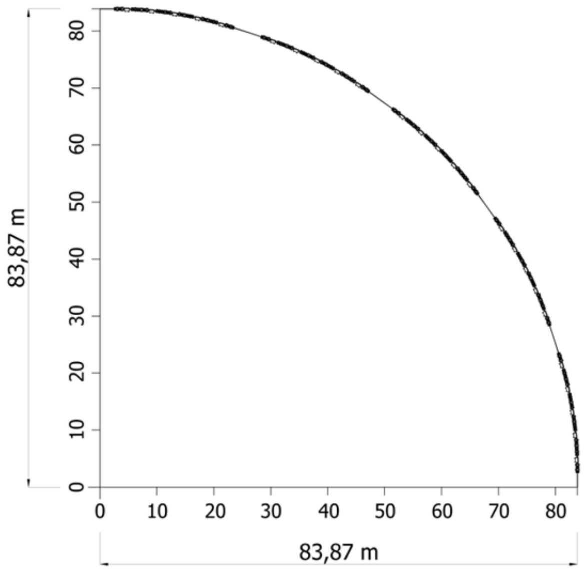

Figure 1: General overview of the one quadrant of ILSF ring.

Figure 2: Top view of the designed 5 BDA lattice.

The main ring parameters are given in Table 1, the optical functions in a super period of ring is shown in Fig. 3 and the corresponding beam envelope is depicted in Fig. 4 respectively.

Table 1: Main Parameters of the ILSF Ring Based on the Second Lattice Option

Parameter	Unit	Value
Circumference	m	528
Nat. emittance	nm.rad	0.477
No. super cell	-	20
Tune (Q_x/Q_y)	-	43.28/14.25
No. dipoles/quad./sext.	-	100/320/320

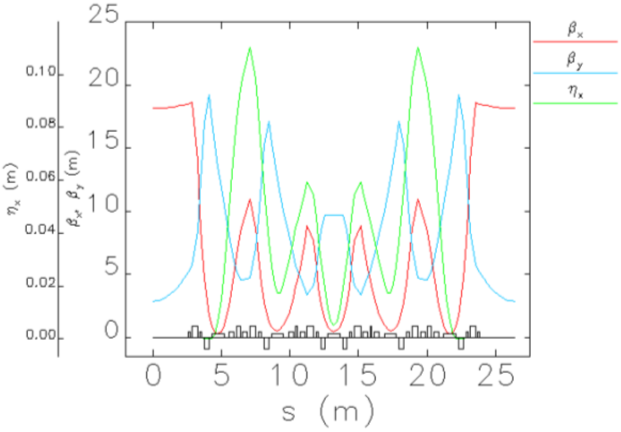

Figure 3: Optical functions in a super period of the ILSF ring.

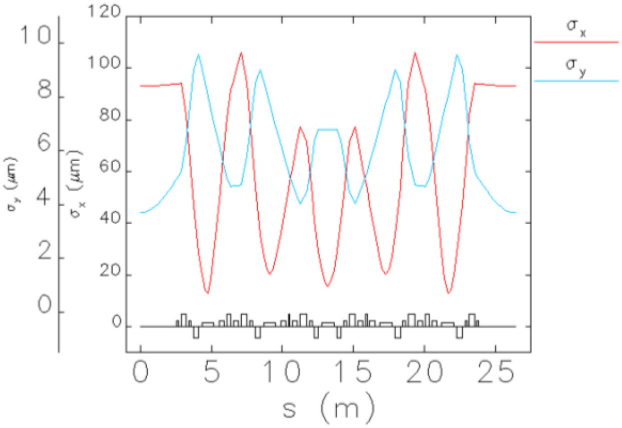

Figure 4: The beam envelope in a super period of the ILSF ring.

NONLINEAR DYNAMICS

To suppress transverse head-tail instabilities and to avoid large tune spread of the off energy electrons, the natural chromaticity is corrected close to a positive value by the use of 16 sextupole magnets within 8 families in each super period. They have been placed at suitable location with proper phase advances in the ring to minimize their nonlinear effects. Then 1000 electrons with Gaussian distribution have been used to track for 5000 turns through the storage ring. Dynamic aperture of the bare lattice at the center of straight section is calculated and the results are depicted in Fig. 5. The corresponding frequency map analysis is depicted in Fig. 6.

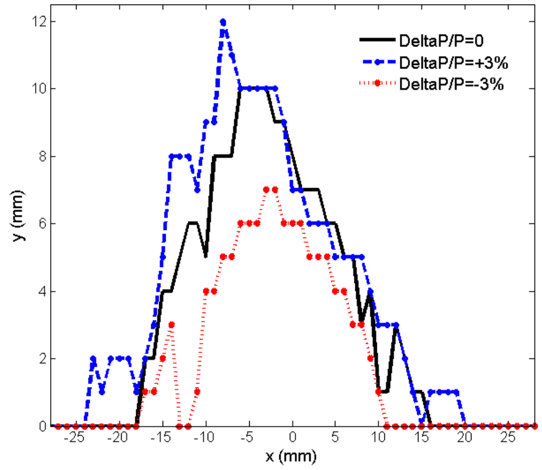

Figure 5: Dynamic aperture at the middle of straight section.

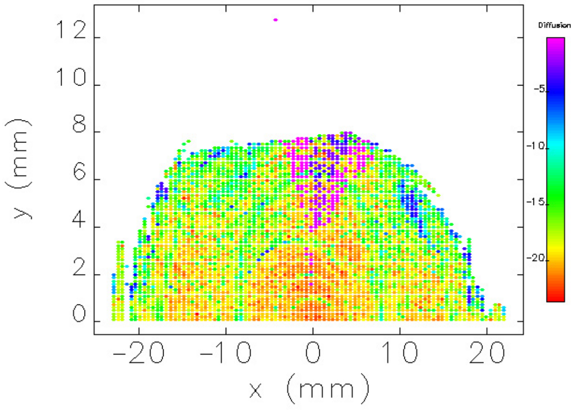

Figure 6: Frequency map analysis of the design ring.

PROPOSED HIGH ENERGY HIGH X-RAY PRODUCTION WITH DIPOLES

The radiated beam critical energy from dipoles is limited to 4.48 keV at 3 GeV. This photon beam energy is useful for several experiments in the soft x-ray region but it is low for the experiments which require high energy hard x-ray. In the initial user mode, to reach the high brilliance radiation with the high energy photons from the dipoles, we replace the central low field dipole magnet in the lattice with a combination of a thin high field (HF) dipole magnet which is sandwiched between the two low field (LF) dipoles. This replacement is shown in Fig. 7 and the corresponding specifications of the magnets are given in Table 2. This is similar to the work have been done in SIRIUS [5] synchrotron light source but with more relaxed magnets.

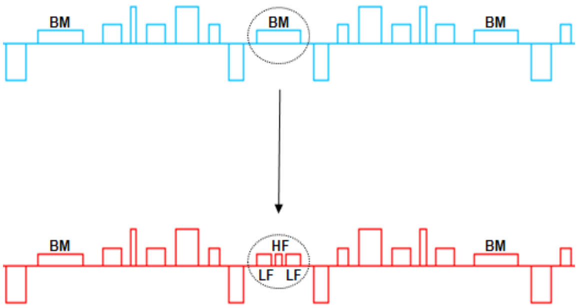

Figure 7: The high field dipole magnet is sandwiched between the two low field dipoles to radiate high energy high brilliance photons. This combination in the red lattice is remarked inside a dash line ellipse.

Table 2: Main Specifications of the High Field (HF) and Low Field (LF) Dipoles

Parameter	**Unit**	**HF**	**LF**
Length	cm	12	28
Bending angle	Deg.	1.200	1.200
Field	T	1.745	0.748
Bending radius	m	5.729	13.369
Gradient	T/m	0.000	0.000

In the first phase of operation, we will use 4 of these inserted high field dipoles for the required high energy photon beam experiments.

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