DESIGNING AN ULTRA LOW EMITTANCE LATTICES FOR IRANIAN LIGHT SOURCE FACILITY STORAGE RING

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Abstract

Electron storage rings are extensively used for high luminosity colliders, damping rings in high-energy physics and synchrotron light sources. To further increase the luminosity at the colliders or brightness of a synchrotron light sources, the beam emittance is being continually pushed downward. In this paper, we investigate the lattice design for the storage ring of Iranian Light Source Facility (ILSF) with an ultra-low emittance, intermediate energy of 3 GeV and circumference of 528 m. We present the design results for a five-band achromat lattice with the natural emittance of 286 pm-rad. The base line is based on 20 straight sections with the length of 7 m.

INTRODUCTION

Storage rings are the principle sources of high brightness photon beams driving the majority of x-ray science experiment in the world today. There has been remarkable progress in the developing these sources over the last two decades. Existing third generation light sources continue to upgrade their capabilities, while new light sources storage rings coming on line with ever improved performances. Since one of the most important factors for the users of a synchrotron radiation is brightness which in the storage ring is determined by the emittance, our aim in this paper is to investigate and present the design results for a lattice in a 3GeV range that can provide high brilliance ultimate storage ring having electrons emittances near X-ray diffraction limited. The diffraction limited light sources performance for a given wave length is met when $\varepsilon=\lambda/((4\pi))$. Accordingly, for hard X-ray radiation at 0.1 nm, $\lambda/4\pi$=8pmrad while for soft X-ray at 1 nm the diffraction limit is 80 pm rad. For the best recently existing storage rings, the horizontal electron beam emittance are nearly tree orders of magnitude larger from diffraction limited for soft X-ray .

One simple and robust method to achieve ultralow emittance is the use of a multibend achromat (MBA) lattice [1,2,3]. The MBA exploits the inverse cubic dependence of emittance on the number of bending magnets. By choosing a very small bending angle per dipole, the emittance can be dramatically reduced. Introducing a vertically focusing gradient in the dipoles causes more reduction in the emittance (the emittance scales inversely with the horizontal damping partition Jx) while the dispersion is limited to small values without requiring any extra space for vertically focusing quadrupoles. To further push down the horizontal emittance, we resort to other well-known methods. For example, we use shorter dipoles at the achromat ends where the dispersion function is matched to the straight section. Considering the mentioned criteria to reach the ultra-low emittance, a five bend achromt lattice has been selected. By this selection, the circumference of storage ring is 528 m and its horizontal emittance is 275 pm rad. The symmetry of lattice is 20 and the length of straight sections is about 7 m. Since the ultra-low emittance lattice can affect the nonlinear beam dynamics, it is needed to examine the dynamic aperture, which may affect beam injection and lifetime. The demanding design feature of modern storage rings, ultra-low emittance and small gap undulator vacuum chambers, cause Touschek scattering and gas scattering to play a major limitation role for beam lifetime. We calculate the Touschek lifetime based on the tracking procedure determining energy acceptance. Small vertical ID gaps is imposed in the tracking procedure. The vacuum life time, in the presence of narrow gap insertion devices is calculated.

LATTICE DESIGN AND LINEAR OPTICS

The storage ring lattice's consists of 20 five-bend achromats separated by 7 m straight sections for IDs. Each of the achromats consists of three unit cells and two matching cells. The unit cells have a 3.9° bending magnet, while the matching cells at the ends of the achromat have a 3.15° bending magnet. three dimentional drawing view of one achromat is shown in Figure 1.

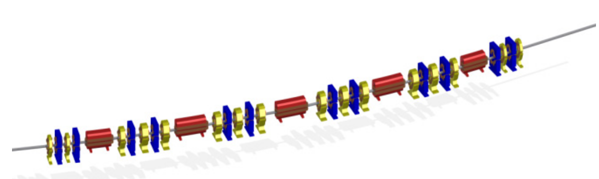

Figure 1: 3D drawing view of one achromat of storage ring lattice magnets.

The matching cells contain dedicated quadrupole doublets in order to match the achromat optics to the ID in the straight sections. Since the vertical focusing is performed by the gradient dipoles, dedicated quadrupoles are, apart from ID matching; only required for horizontal focusing. As mentioned in [3], the emittance of an MBA achromatic cell is mainly determined by the bending angles of the internal unit cells. The lattice functions of one unit cell are shown in Figure 2. The emittance of lattice after matching is 275 pm rad. Fig. 3. shows the lattice functions for one super period of the lattice. The main parameters of the storage ring are listed in Table 1.

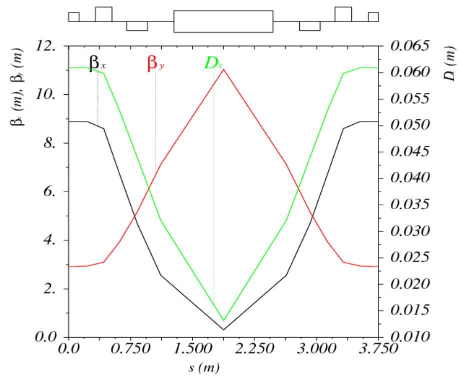

Figure 2: Lattice functions for one-unit cell. The beam is deflected 3.9° through passing each unit cell.

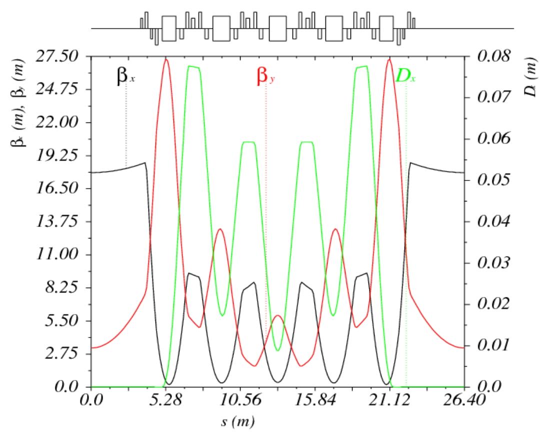

Figure 3: lattice functions in one super period of ILSF storage rings.

Table 1: Main Parameters of ILSF Storage Ring

Parameter	Unit	Value
Energy	GeV	3
Maximum beam current	mA	400
Emittance	nm-rad	275
Circumference	m	528
Length of straight section	m	7
Number of straight section	-	20
Betatron tune (Qx/Qy)	-	44.20/16.18
Natural chromaticity (ξx/ξy)	-	-108 /-61
RF frequency	MHz	100

NONLINEAR OPTICS

Analysis of the charged particle dynamics in the presence of nonlinearities, is generally tackled via Hamiltonian perturbation approach [4,5]. The Hamiltonian of the particle in the transverse plane of the storage ring lattice is decomposed in to a series of different orders, corresponding with different resonance driving terms. The resonance driving terms are then suppressed by properly optimizing the harmonic sextupole strength. This approach has been extensively applied in various electron storage rings, like SLS, DIAMOND, NSLS-II, MAX-IV, [6–11].

Harmonic sextupole strength optimization and particle tracking were performed using the computer codes OPA [12] and AT [13]. Fig.4 shows the dynamic aperture tracking in the middle of straight section for 1000 turns. The results of frequency map analysis for bare lattice is depicted in the Fig. 5 and Fig. 6.

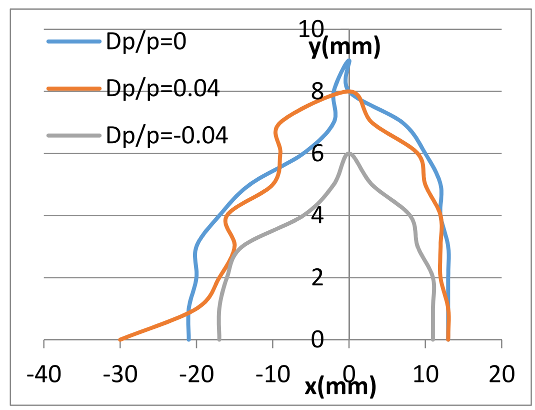

Figure 4: Dynamic aperture tracking for 1000 turns in the middle of straight sections. The tracking of particles has been done for three different energy deviations.

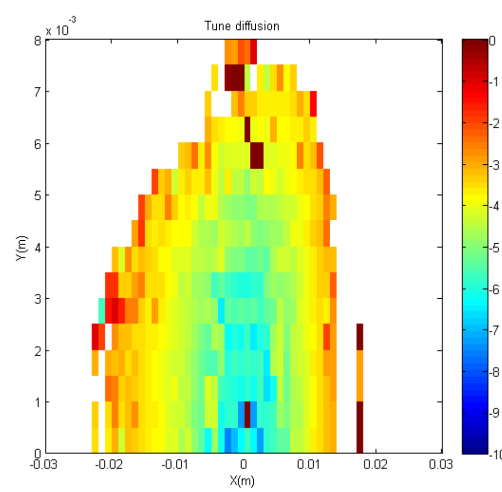

Figure 5: Frequency map analysis of bare lattice for one energy particle.

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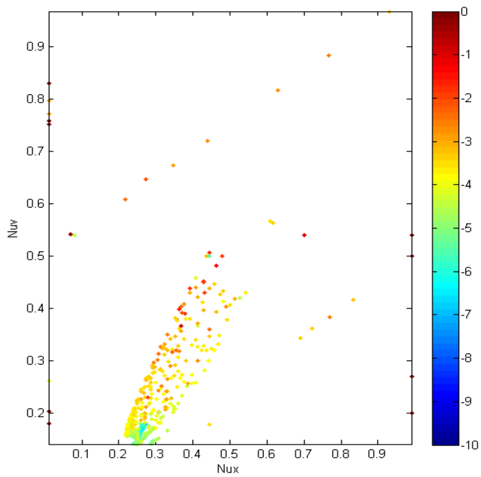

Figure 6: Tune diffusion calculated from frequency map analysis in the resonance diagram.

LIFETIME CALCULATION

The demanding design feature of modern storage rings, ultra-low emittance and small gap undulator vacuum chambers, cause Touschek scattering and gas scattering to play a major limitation role for beam lifetime. We calculate the Touschek lifetime based on the tracking procedure determining energy acceptance. Small vertical ID gaps is imposed in the tracking procedure. In views of particles undergoing scattering with momentum change, we have to calculate momentum acceptance to judge if particle loss or not. For modern light sources, the linear calculation of momentum acceptance is insufficient. it is needed to include the nonlinear variation of twiss parameters and high order dispersion with momentum. vacuum lifetime including, Coulomb and Bremsstruhlang life time, is another component which determines the total lifetime of electrons. Fig.7. shows the variation of vacuum lifetime and total lifetime in different vacuum pressure.

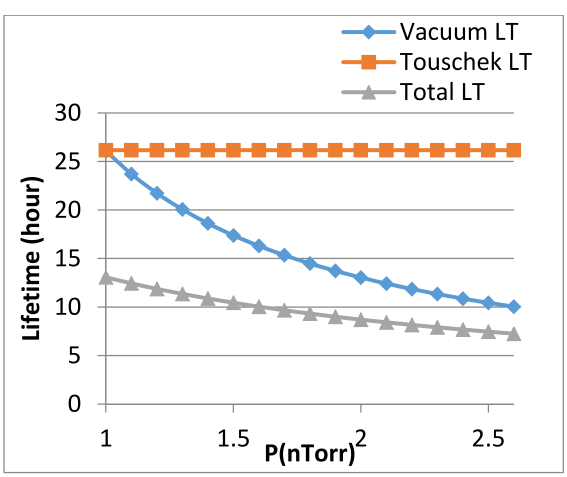

Figure 7: The variation of vacuum and total lifetime with pressure. The Toushchek lifetime is 26 hours.

For typical vacuum pressure of 1.5 nTorr, the total lifetime is about 10 hours.

CONCLUSION

An ultra low emittance for 3 GeV storage ring of ILSF was designed to produce high-brilliant synchrotrn radiation with a few tens KeV for soft and hard X-ray users. The design results showed that the lattice parameters are well within the world landsacape of ultra low emiitance light sources. It is showed that the dynamic aperture which is chalenging point in low emittance rings, is sufficient for safe injection and adequate life time.

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