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BEAM DYNAMICS OF HIGH CHROMATICITY LATTICE FOR IRANIAN LIGHT SOURCE FACILITY (ILSF) STORAGE RING

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Abstract

One of the limiting factors of electron beam lifetime in low emittance storage rings is Head-Tail (HT) instability. Low emittance storage rings typically have a large negative natural chromaticity due to the strong quadrupoles. Above transition large negative natural chromaticity leads to large Head-Tail instability which limit the beam lifetime. Since the threshold current of HT instability is directly related to linear chromaticity, increasing the linear chromaticity to slightly positive value is a solution to prevent HT instability. In this paper we increased the chromaticity of Iranian Light Source Facility (ILSF) to (+4, +4) and we will investigate the beam dynamics of ILSF 3GeV storage ring in high chromaticity. For reaching this aim we have used two families of sextupoles for chromaticity correction and then optimized them to maximize the dynamic aperture and Touschek lifetime. The beam dynamics of high chromaticity lattice is presented in this paper.

INTRODUCTION

One of the main design challenges for a strongly focusing lattice is to obtain adequate dynamic aperture (DA) for injection and Touschek lifetime. One of the most important limiting factors of beam life time in an ultra-low emittance storage ring is chromaticity. Strong focusing storage rings have typically large negative natural chromaticity due to the strong quadrupoles. Large natural chromaticity has deleterious influence on the beam dynamics. It can lead to large tune shifts resulting in crossing of potentially dangerous resonances and in the case of bunched beams the chromaticity produces a transverse instability called Head-Tail (HT) instability. A complete mathematical treatment shows that the growth rate of this instability is much faster for negative than for positive chromaticity values and the threshold current increase with chromaticity [1,2]. Therefore, a method for increasing the threshold current of HT instability and thereby to have a more stable beam, is to operate the storage ring at a higher chromaticity [3].

This paper describes the development of a high-chromaticity optics with linear chromaticity +4 in both transverse planes for the Iranian Light Source Facility (ILSF) storage ring with an ultra-low emittance, energy of 3 GeV and circumference of 528 m.

The storage ring lattice of ILSF 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. The main parameters of the ILSF storage ring for both chromaticity (+1, +1) and (+4, +4) are listed in Table 1.

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Table 1: Main Parameters of ILSF Storage Ring

Parameter	Unit	Chromaticity (+1, +1)	Chromaticity (+4, +4)
Energy	GeV	3	3
Maximum beam current	mA	400	400
Emittance	nm-rad	0.27	0.25
Circumference	m	528	528
Number of super cell	-	20	20
Betatron tune (ν_x/ν_y)	-	44.16/16.22	44.18/16.68
β_x / β_y	m	17.8/3.26	18.405/2.788
Momentum compaction factor (α)	-	1.82×10^{-4}	1.8×10^{-4}
RF frequency	MHz		100

NON LINEARITY

The standard method for optimizing sextupoles of low emittance light sources is based on hamiltonian perturbation approach using resonant driving terms [4].

We have used 6 families of sextupoles for the ILSF 3 GeV storage ring to correct the linear chromaticity, minimize chromatic tune shifts and tailor the chromatic tune footprint while minimizing first-order resonance driving terms. ELEGANT [5] was used to correct the linear chromaticity to +4 in both planes using the two strongest chromatic sextupoles. The sextupole gradients of high chromaticity lattice are given in Fig. 1. We have made a comparison between sextupole gradients of chromaticity (+1, +1) and high chromaticity lattice.

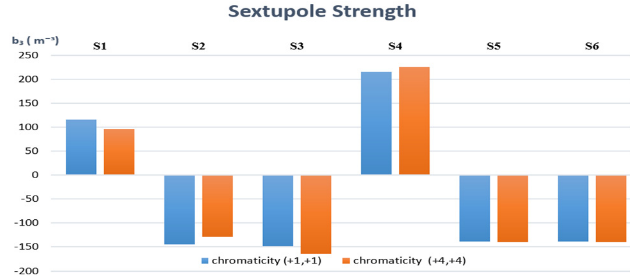

Figure 1: The sextupole gradients for the high-chromaticity optics in comparison to chromaticity (+1, +1).

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The chromatic tune shift for the high chromaticity optics up to ±4% energy deviation is displayed in Fig. 2. The corresponding chromatic tune footprint over the desired energy acceptance is depicted in Fig. 3. The chromatic tune shift of chromaticity (+1, +1) in Fig. 2 is given for comparison [4]. In order to calculate the chromatic tune footprint, the particles have been tracked for 1024 turns in different energy deviation step via ELEGANT code.

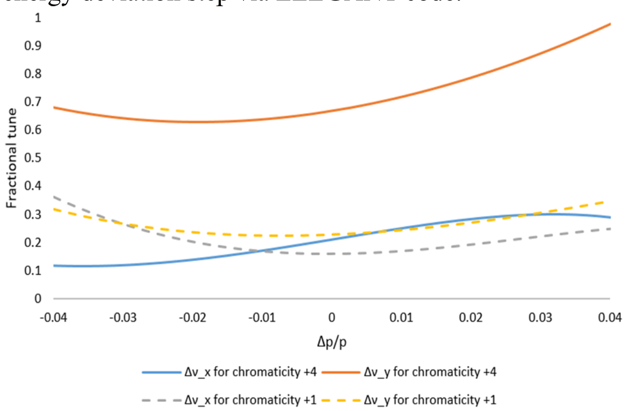

Figure 2: The chromatic tune shift of high chromaticity optics of horizontal and vertical tune with energy in comparison with chromaticity +1. The Elegant code has been utilized for the calculation.

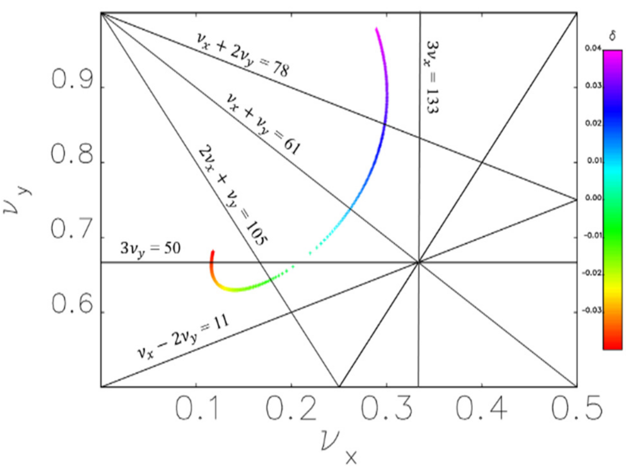

Figure 3: The chromatic tune footprint up to ±4% energy deviation for the high chromaticity optics calculated by Elegant code. Resonances up to third order are displayed.

After optimizing the chromatic tune shift, we evaluate the DA for the high chromaticity lattice. Figure 4 shows the DA tracking results for different energy deviation in the middle of one straight section. For this aim we have tracked particles for 1024 turns and ELEGANT code has been utilize for DA tracking. The DA of chromaticity (+1, +1) for different energy deviation is given for comparison [4].

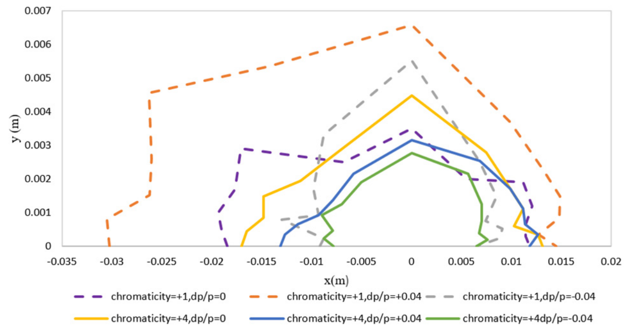

Figure 4: The results of dynamic aperture tracking for different energy deviation in the middle of one straight section.

In order to explore the nonlinear behavior of electrons in detail and find where the limitation of DA originates from, we performed frequency map analysis. A diffusion map for the high chromaticity lattice for on-momentum particles is depicted in Fig. 5 and matches the result for the on-momentum dynamic aperture well. For calculating the FMA we employed ELEGANT code and tracked the on energy particles for 1024 turns. The color bar indicates the tune diffusion rate calculated according to $D = log\sqrt{(\Delta\nu_x)^2 + (\Delta\nu_y)^2}$ where $\Delta\nu_x$ and $\Delta\nu_y$ are the tune shifts between the initial tune and the final tune in the horizontal and vertical planes, respectively. The diffusion rate is a measure of how stable particle motion is. The smaller the diffusion rate the more stable the motion is [6]. At the center of the diffusion map the diffusion is small but it increases towards the boundary of the dynamic aperture. It indicates that by increasing the amplitude, particles cross many resonance lines. The on-momentum dynamic aperture and corresponding diffusion map are almost the same as the results of chromaticity (+1, +1) [4].

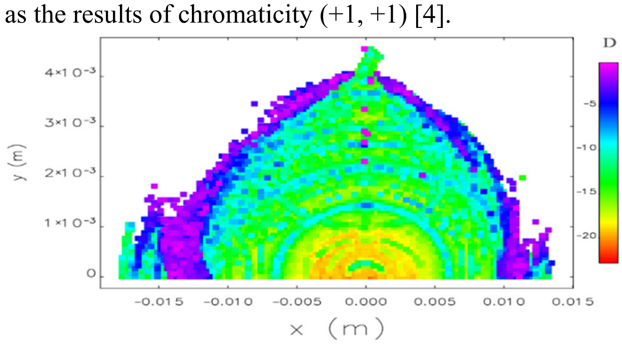

Figure 5: The diffusion map of on energy electrons in the middle of on straight section.

In order to identify exactly which resonance lines have restricted the DA we have calculated tune footprint with amplitude which can be seen in Fig. 6. The calculation has been done with OPA code [7]. The electrons have been tracked for 1024 turns in different amplitude with the step of 0.5 mm in horizontal direction. Particles after crossing the forth order resonance line $2\nu_x + 2\nu_y = 122$ in the amplitude $x = +8mm$ and after that, crossing half integer resonance $2\nu_x = 89$ in the amplitude $x = +10mm$ behave chaotically and finally lost at $x = +11.5mm$. The same

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thing happened for negative direction and eventually the particles lost at $x = -14mm$.

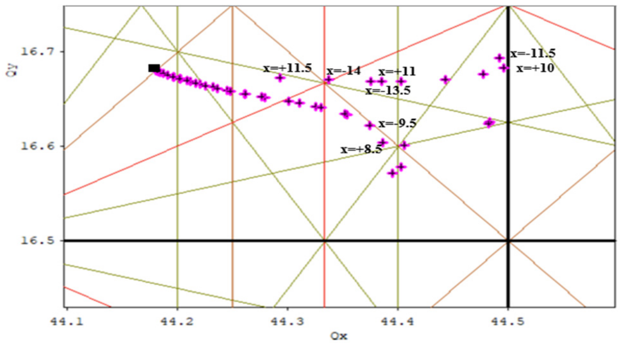

Figure 6: The tune footprint with amplitude of high chromaticity lattice. The electrons have been tracked for 1024 turns for each steps (0.5 mm) of amplitude. The working point is shown by a filled black square. The Opa code utilized for calculation.

TOUSCHEK LIFETIME

One of the major loss mechanisms in an electron storage ring is Touschek scattering which is described by the Touschek lifetime. The most important factor that effects on Touschek lifetime is the overall momentum acceptance around the ring. In order to determine the Touschek lifetime it is therefore necessary to determine the momentum acceptance [6]. The momentum acceptance of the high chromaticity lattice for one super period is depicted in Fig. 7. By using ELEGANT code, a 6-D tracking procedure is employed to determine the energy acceptance of lattice after tracking particles for 1024 turns.

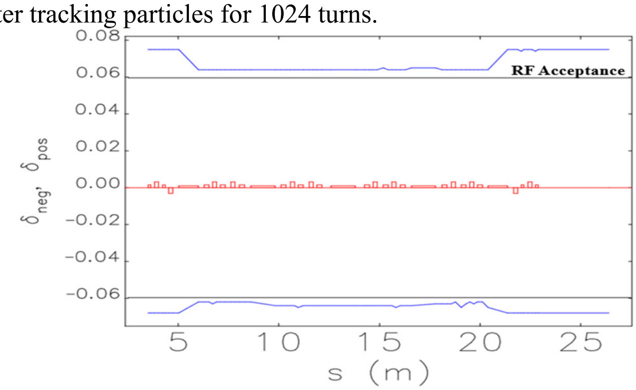

Figure 7: The result of momentum acceptance tracking with 1.1 MV RF peak voltages. The blue curves show lattice positive and negative momentum acceptance.

The Touschek life time of the high chromaticity optics of ILSF storage ring for the maximum stored beam current of 400 mA, coupling of 1% and RF voltage of 1.1 MeV was 60.87 h. Neither the effects of IBS nor the Landau cavities were included in this calculation.

ERROR STUDY

The result of dynamic aperture tracking for 1024 turn with errors for on-momentum particles can be seen in Fig. 8. It is expected that misalignment and multipole errors significantly shrink the dynamic aperture. Although the dynamic aperture is reduced when misalignment errors are added to the lattice, it is still sufficient for off-axis injection. We have used ELEGANT code to calculate the effect of errors on the dynamic aperture. Dynamic aperture calculation has been conducted after applying closed orbit correction.

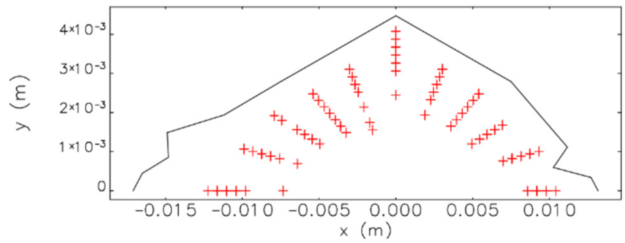

Figure 8: The effect of misalignment error on the dynamic aperture. By employing Elegant code, the tracking has been done for 1024 turns and 20 different seeds.

CONCLUSION

In this paper we have studied the nonlinear beam dynamics of ILSF storage ring at chromaticity (+4, +4). We have used 6 families of sextupole to correct linear chromaticity and optimize resonance driving terms. The results show that the on-momentum DA and corresponding diffusion map is almost the same as design lattice. When errors are included the dynamic aperture is reduced, but the required aperture is still fulfilled. We calculated the MA of the lattice and Touschek lifetime which shows a sufficient Touschek lifetime for high chromaticity optics. Generally, it seems that the lattice performance in chromaticity 4 is sufficient enough to encourage us for further studies to determine the effect of high chromaticity optics on the HT threshold current. There also exist opportunities to further improve high chromaticity optics performance.

REFERENCES

[1] Wilson, Edmund JN, *Nonlinear Resonances*, No. CERN-PS-86-7-AA. CM-P00063722, 1986.

[2] Guiducci, S. *Chromaticity*, No. INFN-LNF--91-031 (R). Istituto Nazionale di Fisica Nucleare, 1991.

[3] Day, Hugo Alistair, *Measurements and Simulations of Impedance Reduction Techniques in Particle Accelerators*, No. CERN-THESIS-2013-083. 2013.

[4] Ahmadi, E., S. M. Jazayeri, and J. Rahighi, “Characterizing and studying the nonlinear beam dynamics performance of Iranian Light Source Facility storage ring”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 927 (2019): 140-150.

[5] M. Borland, “Elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation”, Advanced photon Source, Argonne National Laboratory, USA. Report No. LS-287, 2000.

[6] C. Steier *et al.*, “Measuring and Optimizing the Momentum Aperture in a Particle Accelerator”, Phys. Rev. E 65 (2002) 056506.

[7] A. Streun, OPA Version 3.39, PSI, Switzerland, 2012.