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EMPLOYING OCTUPOLE MAGNETS FOR NONLINEAR OPTIMIZATION OF IRANIAN LIGHT SOURCE FACILITY STORAGE RING

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Abstract

Limited dynamic aperture, resulting from strong nonlinearities in a low emittance storage ring, is a challenging issue from a beam dynamics point of view. In the present study, we have applied three families of focusing and defocusing octupoles to the storage ring lattice with the aim of increasing dynamic aperture and beam lifetime. We have discussed different methods to optimize e position and strength of octupoles so that each family fights a specific resonance driving term.

INTRODUCTION

Storage rings in Light sources are a combination of different types of magnets, including dipoles for bending the beam, quadrupoles for focusing the beam, sextupoles for optimizing chromaticities [1]. In addition to the named magnets, other multipole magnets are used, including octupoles, decapolse and so on, to reduce the number and strength of resonance driving terms (RDTs) [2].

In other words, multipoles play an important role in stabilising beam by suppressing instabilities arising from collective effects like head-tail instability. According to this fact, some light sources and accelerators have employed octupoles in the lattice. For example, MAX IV uses three families of octupoles in its lattic [2, 3]. Moreover, there are several references demonstrating the effect of octupoles in parameters of machine such as dynamic (DA) and momentum aperture (MA), beam lifetime and chromaticity in LHC [4, 5], Tevatron [6], Diamond II [7] and so on. These studies show octupoles can be a vital part of storage rings.

Therefore, octupoles' importance can be considered a motivation to study them in Iranian Light Sorce Facility (ILSF). Hence, in the present study, the way of employing octupole magnets is explained in the next section. The effect of octuples on dynamic aperture and beam lifetime and a brief conclusion summerized in the next two sections.

EMPLOYING OCTUPOLE MAGNETS IN ILSF STORAGE RING

Iranian Light Source Facility (ILSF) is a third generation synchrotron machine working at a current of 400 mA, energy of 3 GeV with a typical equilibrium emittance of 2.7 nm-rad and a vertical emittance of 8 pm rad. ILSF designed as a 5-bend achromat cells, with 7 families of sextupoles, 5 families of quadrapoles and 4 families of dipoles [8]. So far, the effects of octupoles on ILSF storage ring have not been investigated; it is important in other light sources as mentioned before.

For starting this study, there are a few points to deal with such as best place selection for octupoles, the strength of octupoles and optimizing the effect of octupoles on vital parameters including DA, lifetime and RDTs reduction or minimization.

So, we used an alternative way to locate the octupoles in the storage ring, which is based on the betatron function. According to this approach, we consider some RDTs depending on the strength of octupole b_4 and betatron function $\beta_{x,y}$ as follows:

$$h_{22000} = \frac{3}{8} b_4 \beta_x^2 J_x^2$$
$$h_{11110} = -\frac{3}{2} b_4 \beta_x \beta_y J_x J_y$$
$$h_{11002} = \frac{6}{4} b_4 \eta^2 \delta^2 \beta_x J_x$$
$$h_{00112} = -\frac{6}{4} b_4 \eta^2 \delta^2 \beta_y J_y$$

Where η is dispersion function and J is amplitude of oscillation. Furthermore, other terms named amplitude dependent tune shift (ADTS) are as follows:

$$\frac{\partial \Delta\nu_x}{\partial J_x} = \frac{3}{8\pi} b_4 \beta_x^2$$
$$\frac{\partial \Delta\nu_y}{\partial J_y} = \frac{3}{8\pi} b_4 \beta_y^2$$
$$\frac{\partial \Delta\nu_x}{\partial J_y} = \frac{\partial \Delta\nu_y}{\partial J_x} = -\frac{3}{4\pi} b_4 \beta_x \beta_y$$

and

$$\xi_{x,y}^{(2)} = \frac{1}{2} \frac{\partial^2 \Delta\nu_{x,y}}{\partial \delta^2} = \pm \frac{3}{4\pi} b_4 \eta^2 \beta_{x,y}$$

Where $\xi_{x,y}^{(2)}$ is second order chromaticity [9].If octupoles to be placed properly, an octupole family intended to correct horizontal (or vertical) tune shifts and fight a specific driving term. For this purpose, we locate OCT1 (OCT3) in a location where $\beta_x \gg \beta_y (\beta_y \gg \beta_x)$. For the case of the coupling term $\frac{\partial \Delta\nu_x}{\partial J_y} = \frac{\partial \Delta\nu_y}{\partial J_x}$, an ideal location of the octupole named OCT2 would be where $\beta_x \approx \beta_y$.

On the other hand, when octupoles used to fight ADTS see large dispersion resulting in large chromatic tune shifts

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creation which have to be counteracted again by a family octupoles. Therefore, choosing a dispersion-free location for the placement of the octupole families used to counteract ADTS. According to documents, this separation of function among different octupole families help us to ensure the strengths of octupole should be low [10]. Locating octupoles in the lattice, we obtained their magnitude by trial and error using OPA. Octupoles with zero length, but initial strength, were placed in the ILSF lattice as follows:

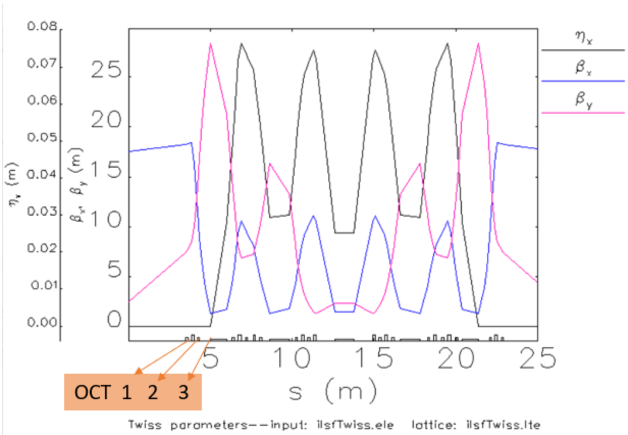


Figure 1: location of octupoles in the ILSF lattice. The positions of OCT 1, OCT 2 and OCT 3 are before Q11, after S2 and before be1, respectively.

Table 1 shows the characteristics of octupoles.

Table 1: The Characteristics of Octupoles.

Octupoles	OCT1	OCT2	OCT3
Strength (Tm^{-3})	792.138	-1124.800	-538.818
Length	0	0	0

THE EFFECT OF OCTUPOLES ON DYNAMIC APERTURE AND BEAM LIFETIME

According to the importance of DA and beam lifetime, the effect of employing octupoles is investigated respectively.

Effect on Dynamic Aperture

The region in the transverse plane where the particle motion is stable for a given number of turns is dynamic aperture (DA). When this area is enough large, the life span of the beam will increase; however, this area can be reduced under the influence of nonlinearities. Besides, the relation between the strength of the octupoles is defined as:

$$A_{dyna,oct} = \sqrt{2J_{max,oct}\beta_x(s)} = \frac{\sqrt{\beta_x(s)}}{\beta_x(s_2)}\left(\frac{\rho}{|b_4|L}\right)$$

Where J is the maximum amplitude in the presence of octupole, s_2 and b_4 is the octupole locations and strength, respectively. Moreover, L and ρ is the length of the ring and the radius of curvature. Based on this equation, there is an inverse relation between DA and the strength of octupole magnet. This relation justifies why the strength of octupole should be low. The overall stable region under the influence of all multipoles (sextupoles, octupoles and so on) is written in a simplified form as below [11, 9]

$$A_{dyna,total} = \frac{1}{\sqrt{\sum_i \frac{1}{A_{dyna,sext,i}{}^2} + \sum_j \frac{1}{A_{dyna,oct,j}{}^2} + \cdots}}$$

We simulate the DA of ILSF in the presence of octupoles in OPA. In this process we have to change the working point from (44.18, 18.28) to (44.29, 18.17) to find the best stable area as at this point the tune footprint was long and crossed a couple of resonances line. After employing octupoles in lattice, changing the working point and optimization of ILSF parameters, we find a new short tune footprint confirming stable working point of machine. Figure 2 shows the tune footprint before and after employing octupoles.

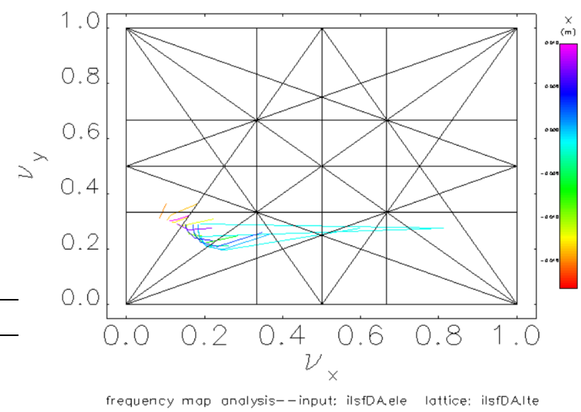
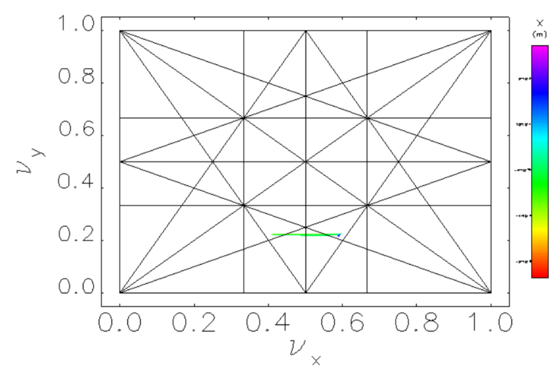


Figure 2: a) Tune footprint before employing octupoles in lattice.



b) Tune footprint after employing octupoles in lattice.

In the mentioned condition the horizontal DA change from (-13 mm, 11 mm) to (-15 mm to 12 mm) approximately which is demonstrated in Figure 3: DA of ILSF in the presence of octupoles. The blue line shows the element apertures and the red line shows the DA of ILSF.

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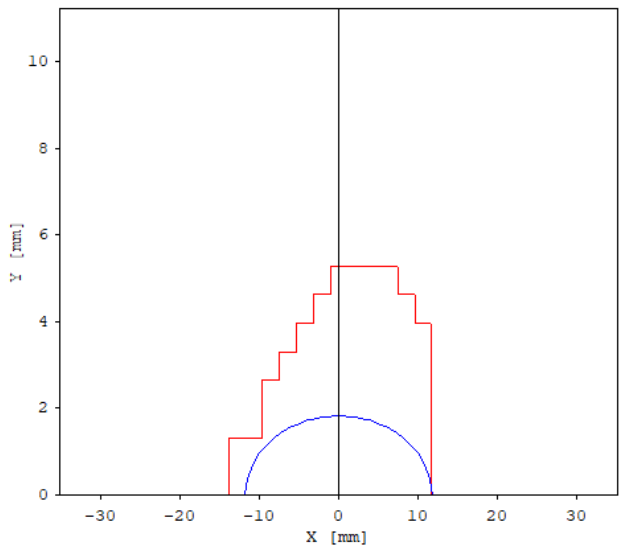

Figure 3: DA of ILSF in the presence of octupoles. The blue line shows the element apertures and the red line shows the DA of ILSF.

The maximization of DA can be a result of RDTs or ADTS reduction coming in Figure 4.

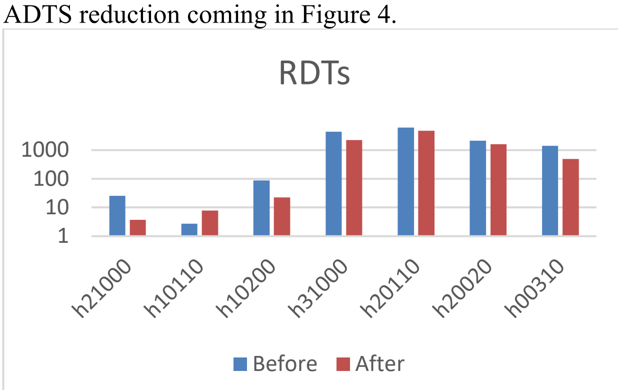

Figure 4: The amount of RDTs before and after of octupole presence in ILSF. Vertical axis is logarithmic.

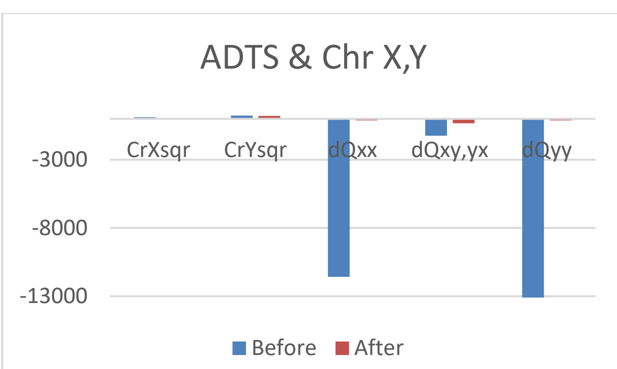

Figure 5: The amount of ADTS before and after of octupole presence in ILSF.

According to these figures, the final result of employing octupoles in lattice is DA expansion. DA expansion needed to simulate so that the strength of octupoles remain low. In fact, in high strength of octupoles, the footprint may be short and passes a few resonances line, but the DA is small. The observed effect is due to an inverted relation between octupole strength and DA, as demonstrated inequation 9.

Effect on Beam Lifetime

The lifetime of the beam in the electron storage ring is mainly influence by two mechanisms of electron scattering and Touschek scattering which is described by $\frac{1}{\tau} = \frac{1}{\tau_t} + \frac{1}{\tau_v}$. Where τ is the total lifetime of the beam, τ_t is the Touschek lifetime and τ_v in total represents the lifetime due to elastic and inelastic scattering of the beam-gas [1]. We obtained 6.340 h and 6.580 h for lifetime of particles in the absence of octupoles/ presence of octupoles in total current of 400 mA, for 100 bunch and 176 harmonics.

CONCLUSION

According to this study, employing octupoles in storage ring results in expansion of horizontal DA from -15 mm to 12 mm and an increase in beam lifetime.

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