COMPENSATION OF NONLINEARITIES IN NICA COLLIDER OPTICS

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Abstract

The Nuclotron-based Ion Collider fAcility (NICA) [1] is a new accelerator complex being constructed at JINR. It is designed for collider experiments with ions and protons and has to provide ion-ion (Au^{79+}) and ion-proton collisions in the energy range 1÷4.5 GeV/n and collisions of polarized proton-proton and deuteron-deuteron beams.

Different chromaticity correction schemes involving several families of sextupoles are considered for two collider conceptions: with constant γ_{tr} and with changeable one.

INTRODUCTION

The collider rings has the racetrack shape and consist from two arcs and two long dispersionless straight sections with two IPs. The normalized chromaticity reaches a high value ~4.

Therefore the quite strong chromatic sextupoles magnets on arcs are required which in turn bring significant non-linear distortions in beam dynamics. Different schemes involving several families of sextupoles and are tested. Optimization of the chromaticity correction scheme was carried out to increase the dynamic aperture.

CHROMATICITY CORRECTION SCHEMES

Triplet based racetrack with γ_{tr}=6.22

This option was considered in Ref. [2] (see Fig.1).

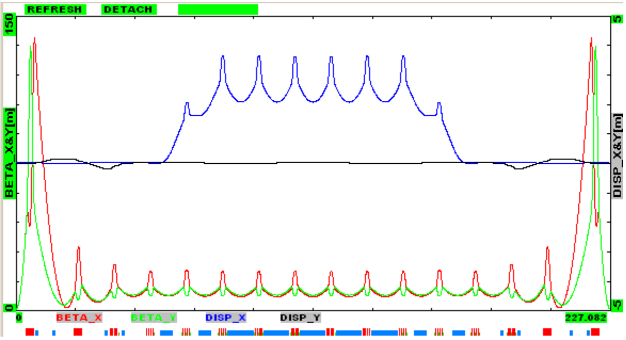

Figure 1: β-function & dispersions for half of the ring.

A chromaticity correction includes 4 families of sextupoles (2 focusing and 2 defocusing ones). It allows one to correct both the tune chromaticity and the beta-function chromaticity excited by IP quadrupoles. Sextupoles of each family are located with 180° betatron phase advances for their nonlinearity compensation. The dependence of the collider tune on Δp/p is shown in Fig. 2. It is very nonlinear due to large β^* which excites large tune and β-function chromaticity.

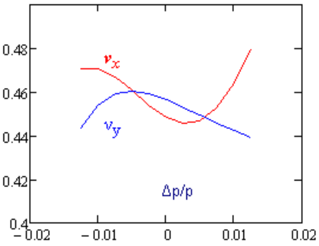

Figure 2: Tune dependence on the momentum offset.

The natural chromaticity of the ring are: ξ_x=-27.1, ξ_y=-23.2 ($\Delta\xi_{x,y}$ ~ −17 from two IPs). Corrected chromaticities are: ξ_x = −1.54, ξ_y = −1.50. The sextupole strength is ~0.35 kG/cm^2. A non-linear dependence of tunes and β-functions on Δp/p and the optics smoothness requirement do not allow the perfect chromaticity correction. However sextupole settings making reasonably good compensation were found (see Fig. 3).

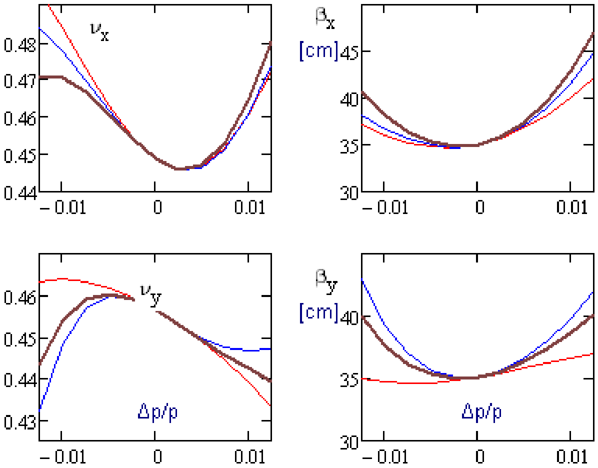

Figure 3: Dependence of the tune and β^* on Δp/p with different sextupoles strength.

That allowed us to avoid adding octupoles. Note also that the nonlinearity of tunes is actually profitable. It allows us to have large tune chromaticity required for transverse instabilities suppression with moderate tune variation across the momentum aperture.

FODO-cell based racetrack with changeable γ_{tr}

To meet the NICA requirements of operation with different magnetic rigidity beams, Au-ions in range 1÷4.5 GeV/u and with proton 6÷13 GeV lattice with changeable transition energy was considered.

1. *Au 4.5 Gev/u mode (see Fig. 4)*

Only sextupoles located in two central superperiods (without dispersion supressors) plus four additional sextupoles (instead of multipole correctors) are used for correction (see Fig. 5).

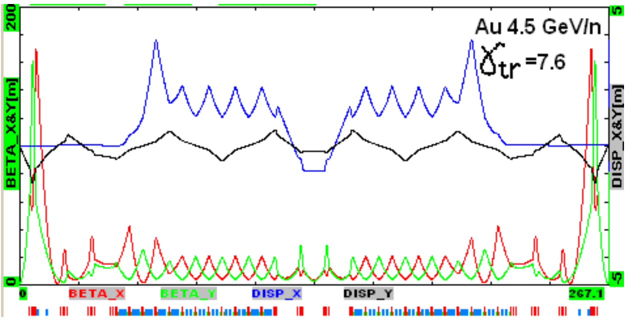

Figure 4: β-function & dispersions for half of the ring for Au 4.5 GeV/n

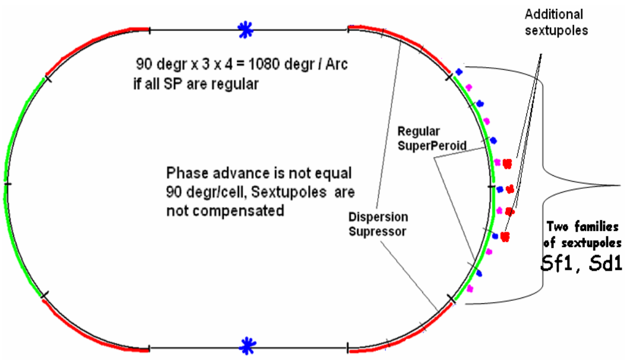

Figure 5: Chromaticity correction scheme for Au 4.5 GeV/u option (arcs without straight insertions)

2. *Au 3.5 GeV/u, Au 1.5 GeV/u modes (see Fig 6)*

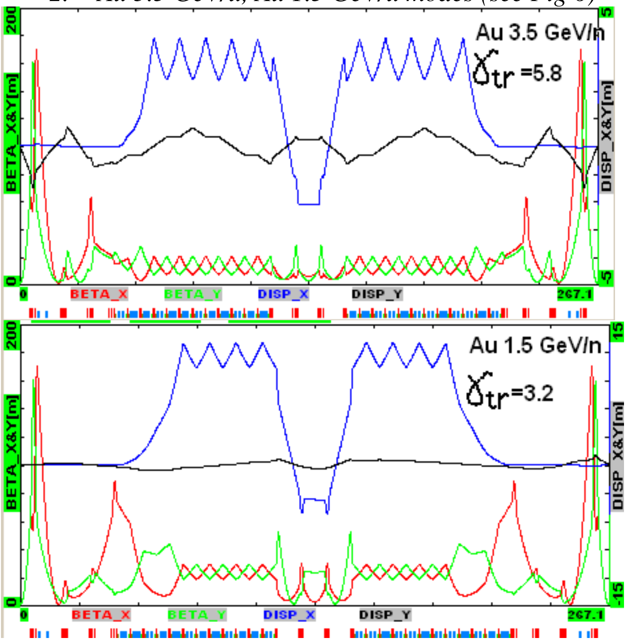

Figure 6: β-function & dispersions for half of the ring for Au 3.5 & 1.5 GeV/u

All sextupoles in the arc (near each quad) are used for chromaticity correction.

3. *Protons 12.45 GeV mode (see Fig 7)*

In the proton mode the number of cells in one superperiod N_{cell} and the number of superperiods S_{arc} per arc are dictated by the required betatron phase advance in the horizontal plane. Following the theory of resonant lattices [4], we construct a lattice with the horizontal betatron phase advance in the arc ν_{arc} as close to the number of superperiods S_{arc} as possible keeping them both being integers. This means that the phase advance in one superperiod should be $2\pi\nu_{arc}/S_{arc}$, and the phase advance of radial oscillations between the cells located in different superperiods and separated by $S_{arc}/2$ superperiods is $2\pi\cdot\frac{\nu_{arc}}{S_{arc}}\cdot\frac{S_{arc}}{2}=2\pi\cdot\frac{\nu_{arc}}{2}=\pi+2\pi n$. It corresponds to the condition of first-order compensation for the nonlinear effects of sextupoles in the arcs.

Only sextupoles near central lenses (four families) in each superperiod (where dispersion function of the lattice are positive) are used (see Fig 8).

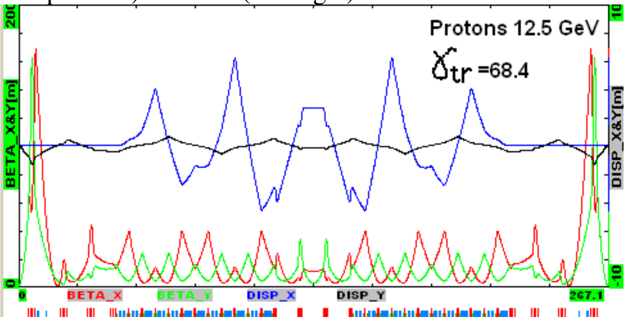

Figure 7: β-function & dispersions for half of the ring for 12.45 GeV Protons option

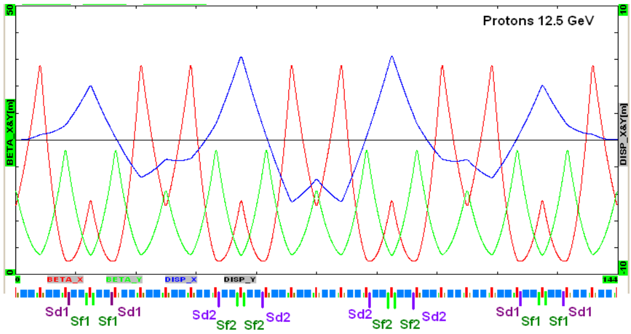

Figure 8: Chromaticity correction scheme for proton 12.45 GeV option (arc without straight insertion)

Parameters of the sextupoles are shown in the Table 1.

Table 1. Parameters of sextupole lenses

	Sextupoles strength [kG/cm^2] /Number per arc				Ring crom (before corr), ξ_x / ξ_y	Ring crom (after corr), ξ_x / ξ_y
	Sf		**Sd**			
Au 4.5 GeV/n	0.154 / 8		-0.264 / 8		-38.3 / -36.6	0.11 / -0.15
Au 3.5 GeV/n	0.054 / 12		-0.085 / 12		-29.6 / -32.4	0.12 / -0.18
Au 1.5 GeV/n	0.011 / 12		-0.130 / 12		-28.8 / -27.5	0.24 / 0.04
Proton 12.45 GeV	**Sf1**	**Sf2**	**Sd1**	**Sd2**	-37.2 / -33.5	-0.005 / -0.27
	0.072 /4	0.110 /4	-0.207 /4	-0.284 /4		

Dependences of the ring tune via Δp/p are presented in Fig. 9.

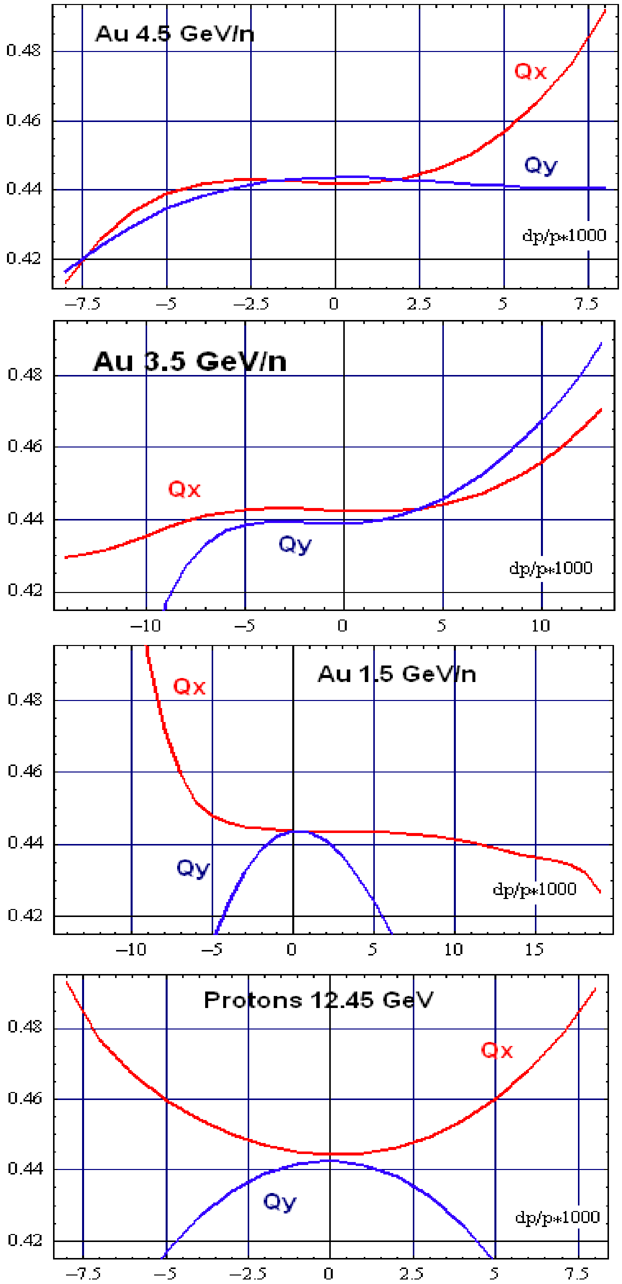

Figure 9: Collider rings tune via *dp/p*

The ring tunes have non-linear dependence on Δp/p especially for Au 1.5 GeV/n and Protons options. Thus, may be, adding of the octupoles is needed. However in the region of momentum acceptance Δp/p ±0.005 the tunes have acceptable values to avoid crossing of dangerous resonances (especially half-integer).

Due to high total length of straight sections (relatively to all ring perimeter) NICA collider has sufficiently high normalised chromaticity value $\xi_{x,y}/\nu_{x,y} \sim 4$, and use of quite strong sextupole magnets for chromaticity correction sharply restricts the dynamic aperture.

Dynamic aperture of the collider is calculated by tracking through the ring optics in MAD and OptiM codes.

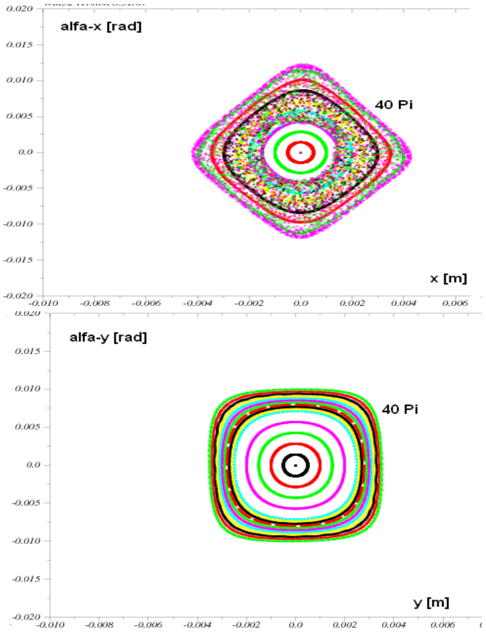

Figure 10: Dynamic aperture in the transverse phase planes for *Au 4.5 GeV/n*

Thus the scheme of chromaticity compensation for all working options of NICA collider is presented. Ist developed to reduce the sextupole nonlinearities in the ring as much as possible, ensures achievable values of the sextupole magnets strength and acceptable dynamic aperture of the collider to get the desirable luminostity 10^{27} cm^{-2}s^{-1} for Au- collisions and 10^{30} cm^{-2}s^{-1} for proton collisions.

REFERENCES

[1] G. Trubnikov et al., “Project of the Nuclotron-based Ion Collider fAcility (NICA) at JINR, Proceedings of RuPAC 2008, Zvenigorod, Russia.

[2] V. Lebedev, “NICA: Conceptual proposal for collider”, MAC2010, January, 2010.

[3] Yu. Senichev and A. Chechenin, Theory of “Resonant” Lattices for Synchrotrons with Negative Momentum Compaction Factor, Journal of Experimental and Theoretical Physics, December 2007, vol. 105, No. 5, pp. 1127–1137.