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 \(\gamma_{tr}\) 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 \(\sim4\).

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 \(\gamma_{tr}=6.22\)

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

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 \(\Delta p/p\) is shown in Fig. 2. It is very nonlinear due to large \(\beta^*\) which excites large tune and \(\beta\)-function chromaticity.

FODO-cell based racetrack with changeable \(\gamma_{tr}\)

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 suppressors) plus four additional sextupoles (instead of multipole correctors) are used for correction (see Fig. 5).
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 \( \nu_{arc} \) 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 \( 2\pi \nu_{arc}/S_{arc} \). 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).

Parameters of the sextupoles are shown in the Table 1.

<table>
<thead>
<tr>
<th>Sextupoles strength [kG/cm^2]</th>
<th>/Number per arc</th>
<th>Ring crom (before corr), ( \xi_x / \xi_y )</th>
<th>Ring crom (after corr), ( \xi_x / \xi_y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au 4.5 GeV/n</td>
<td>0.154 / 8</td>
<td>-0.264 / 8</td>
<td>-38.3 / -36.6</td>
</tr>
<tr>
<td>Au 3.5 GeV/n</td>
<td>0.054 / 12</td>
<td>-0.085 / 12</td>
<td>-29.6 / -32.4</td>
</tr>
<tr>
<td>Au 1.5 GeV/n</td>
<td>0.011 / 12</td>
<td>-0.130 / 12</td>
<td>-28.8 / -27.5</td>
</tr>
<tr>
<td>Proton 12.45 GeV</td>
<td>0.072 / 4</td>
<td>-0.207 / 4</td>
<td>-37.2 / -33.5</td>
</tr>
<tr>
<td></td>
<td>0.110 / 4</td>
<td>-0.284 / 4</td>
<td>-33.5 / -30.5</td>
</tr>
<tr>
<td></td>
<td>0.04</td>
<td>-0.005</td>
<td>-0.27</td>
</tr>
</tbody>
</table>
Dependences of the ring tune via $\Delta p/p$ are presented in Fig. 9.

The ring tunes have non-linear dependence on $\Delta p/p$ 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 $\Delta p/p \pm 0.005$ 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 $\xi_{x,y}/v_{x,y}\sim 4$, 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.

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 luminosity $10^{27}$ cm$^{-2}$s$^{-1}$ for Au- collisions and $10^{30}$ cm$^{-2}$s$^{-1}$ for proton collisions.

REFERENCES

