The Correction System of the NICA Booster Guiding Magnetic Field

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INTRODUCTION

The NICA accelerator complex consists of two injector chains, a new 25 T*m superconducting (SC) booster synchrotron (Booster), the existing SC synchrotron – Nuclotron, the new SC collider that has two storage rings each of about 503 m in circumference and beam transfer lines. Construction of the Booster was finished in 2020 and the first machine Run with ion beam was successfully carried out in December. So far, three commissioning Runs with various ion beams have been successfully completed. One of the first procedures after beam injection is the closed orbit correction and providing stable circulation. The closed orbit distortion is should not be out of the tolerance range during the accelerating cycle. The influence of the fringe fields and the lattice elements errors (nonlinearities and integral field value errors, misalignment of the elements etc.) and natural chromaticity should be corrected by the correction system. Dynamic aperture (DA) is one of the key characteristics for any accelerator facilities. The estimation of the lattice elements errors and beam correction system influence at DA are the milestone stages during construction of the facility. The main parameters, arrangements and the field calculations of the corrector magnets, the closed orbit correction algorithms in superconducting synchrotrons, which can be implemented in the Booster, the tuning processes, the study of the beam parameters and optical characteristics of the Booster during Runs are presented. The methods of the DA calculation for the NICA Booster in MAD-X software among other factors including symplectic tracking algorithm PTC (Polymorphic tracking code) are also described.

SUPERCONDUCTING BOOSTER SYNCHROTRON

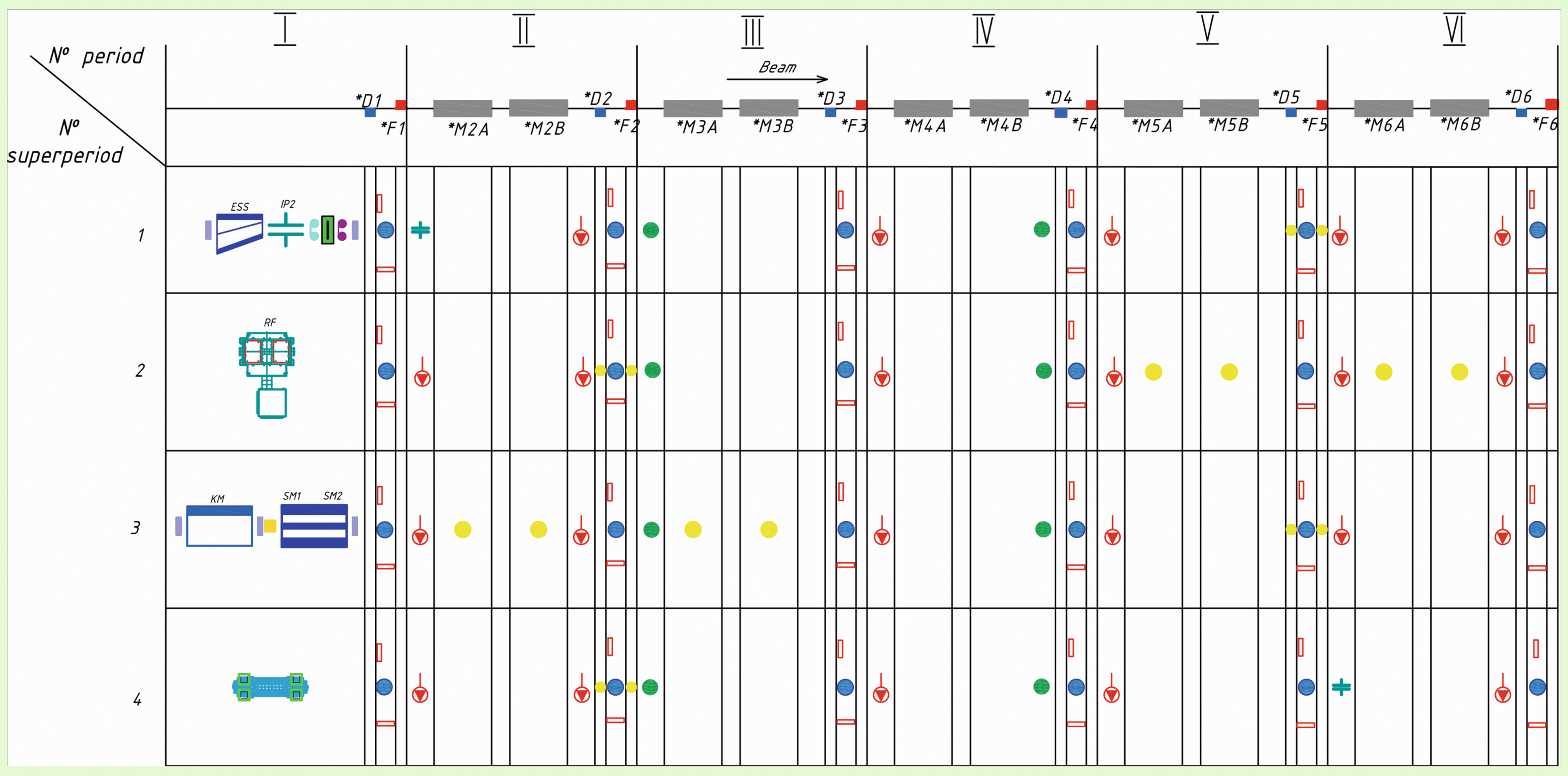

Figure 1: The Booster lattice structure. The numbers of superpriods (left) and DFO-cells (top) are shown. The following elements are highlighted in color: dipole correctors (blue circle), multipole correctors (green circle) and BPMs (red hollow rectangle)

Booster lattice (Fig. 1) consist of 4 superperiod. Each superperiod includes five DFO-cells with two sector dipole magnets, one defocusing and one focusing lenses and one missing dipole cell with one defocusing and one focusing lenses. The correction system system includes 24 dipole (12 horizontal and 12 vertical) and 8 multipole corrector magnets. The optical functions of the facility superperiod are shown in Figure 2. The Booster main parameters are given in Table 1.

Table 1: The Booster main parameters

Parameters	Value
Working energy $^{197}_{31}Au$, MeV/u	3.2/578
Betatron tune Q_x/Q_y	4.8/4.85
Natural chromaticity ξ_x/ξ_y	-5.10/-5.50
Momentum spread (injection) $\Delta p/p_0$	$\pm 10^{-3}$
BPM number (hor./vert.)	24/24
Dipole correctors number (hor./vert.)	24/24
Multipole correctors number	8

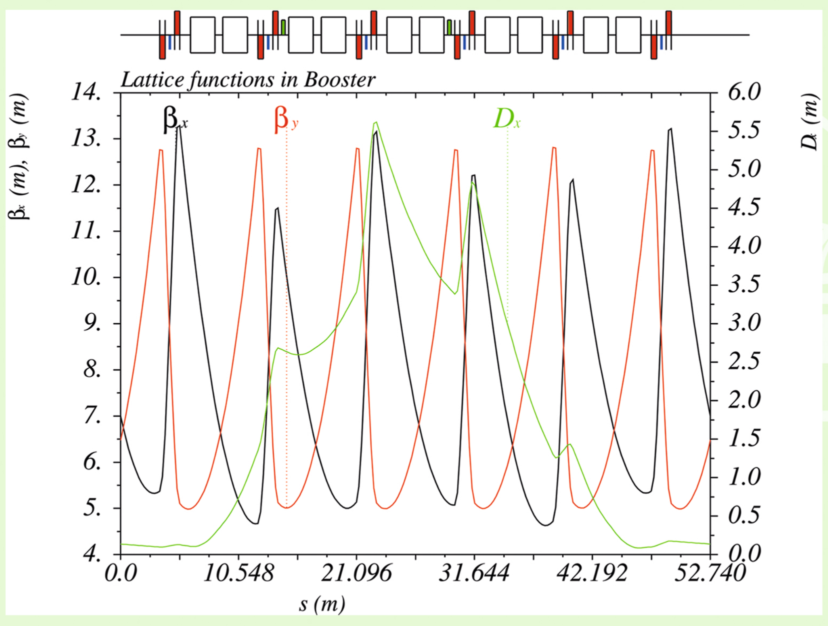

Figure 2: The optical functions of the Booster superperiod

CORRECTION SYSTEM

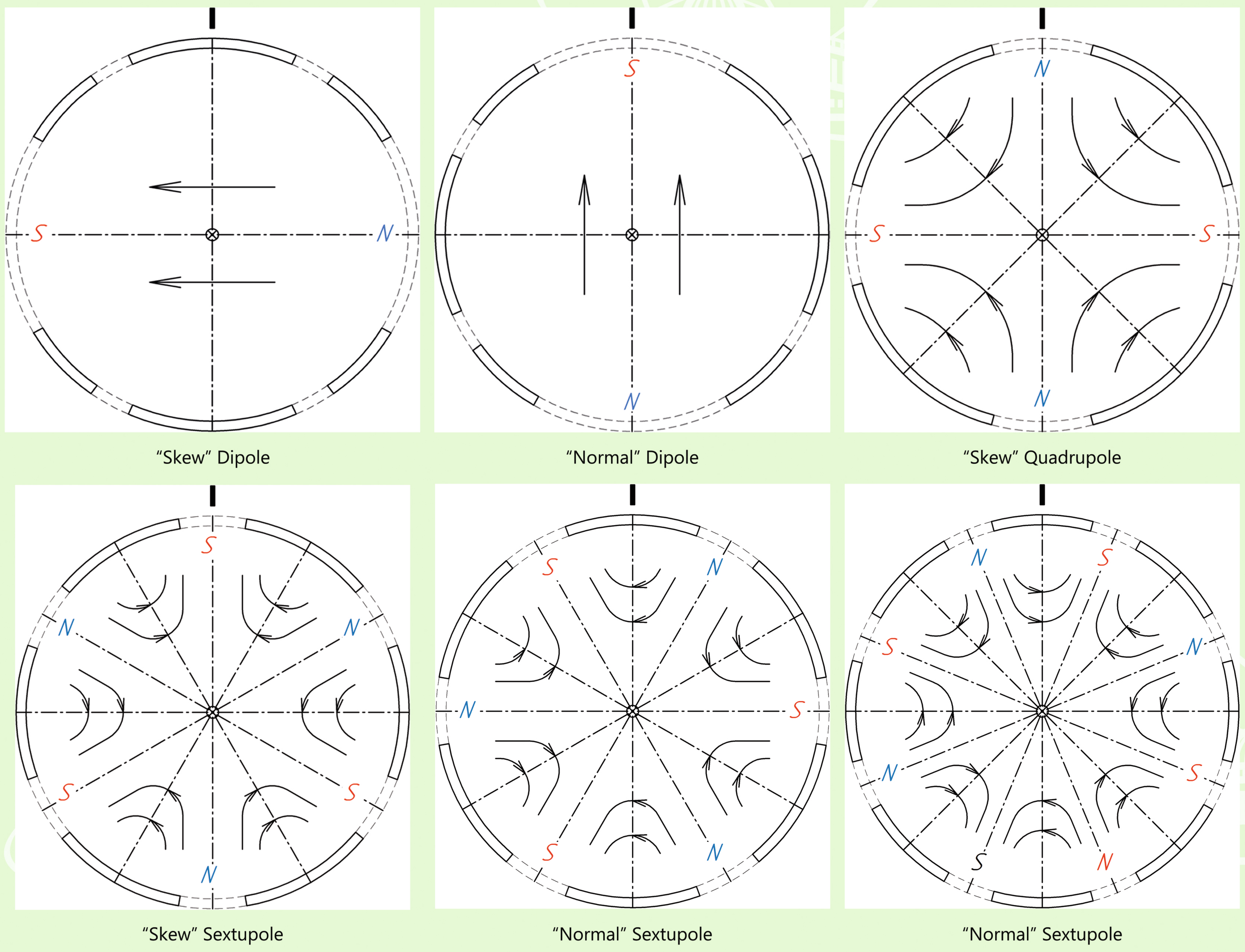

Figure 3: The design of the Booster correctors coils

FIELD CALCULATIONS

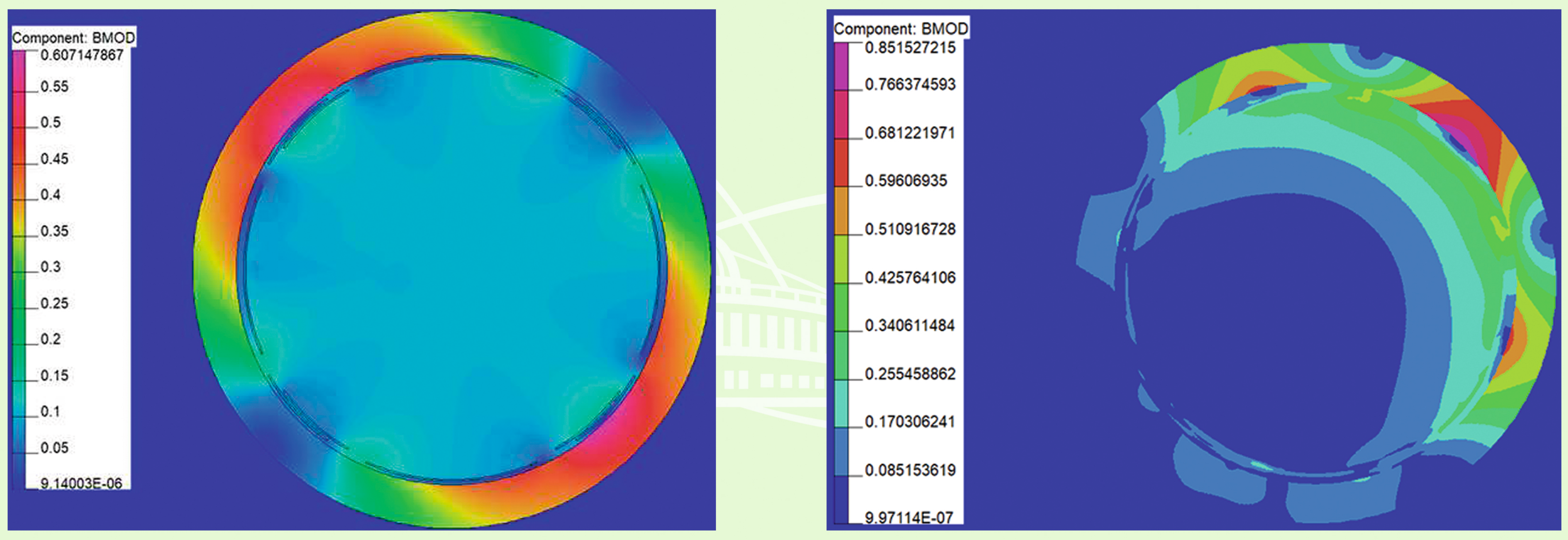

Figure 4: The calculations of Bmod component for the Booster correctors (2D FEM): dipole (left) and multipole (right)

Table 2: Aims of the corrector systems

Field Type	Correction goals	Field	Ampere-turns
"Normal" dipole (b_0)	Horizontal orbit	0.08 T	5500
"Skew" dipole (a_0)	Vertical orbit	0.08 T	5500
"Skew" quadrupole (a_1)	Betatron tune coupling	0.6 T/m	4200
"Normal" sextupole (b_2)	Chromaticity	130 T/m²	3900
"Skew" sextupole (a_2)	Fringe field influence	130 T/m²	3900

Table 3: Field calculations @R = 30 mm [T]

Calculation	Dipole (b_0, a_0)	Quadrupole (b_1, a_1)	Sextupole (b_2, a_2)	Octupole (b_3)
Analytic (vacuum)	0.03857	0.01676	$7.413 \cdot 10^{-3}$	$2.007 \cdot 10^{-3}$
FEM 2D (vacuum)	0.03486	0.01661	$7.451 \cdot 10^{-3}$	$2.010 \cdot 10^{-3}$
δ	10.51	0.91	0.50	0.17
Analytic (yoke)	0.07204	0.03239	0.01342	$3.321 \cdot 10^{-3}$
FEM 2D (yoke)	0.07334	0.03232	0.01336	$3.313 \cdot 10^{-3}$
δ	1.78	0.21	0.42	0.17

RESULTS

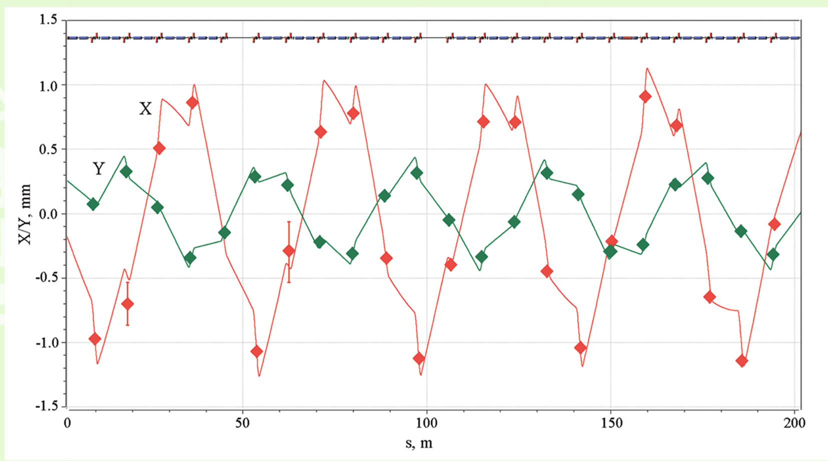

Figure 5: Calculations (line) and measurements (points) of differential orbits

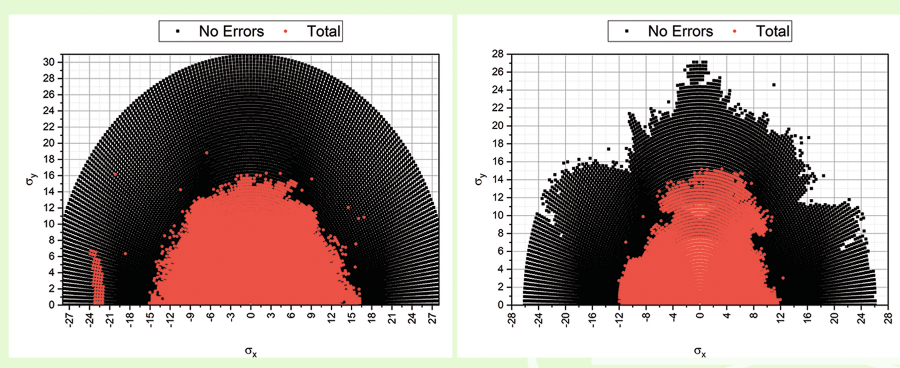

Figure 6: The 4D DA when sextupole correctors are switched off (left) and on (right) at the injection energies

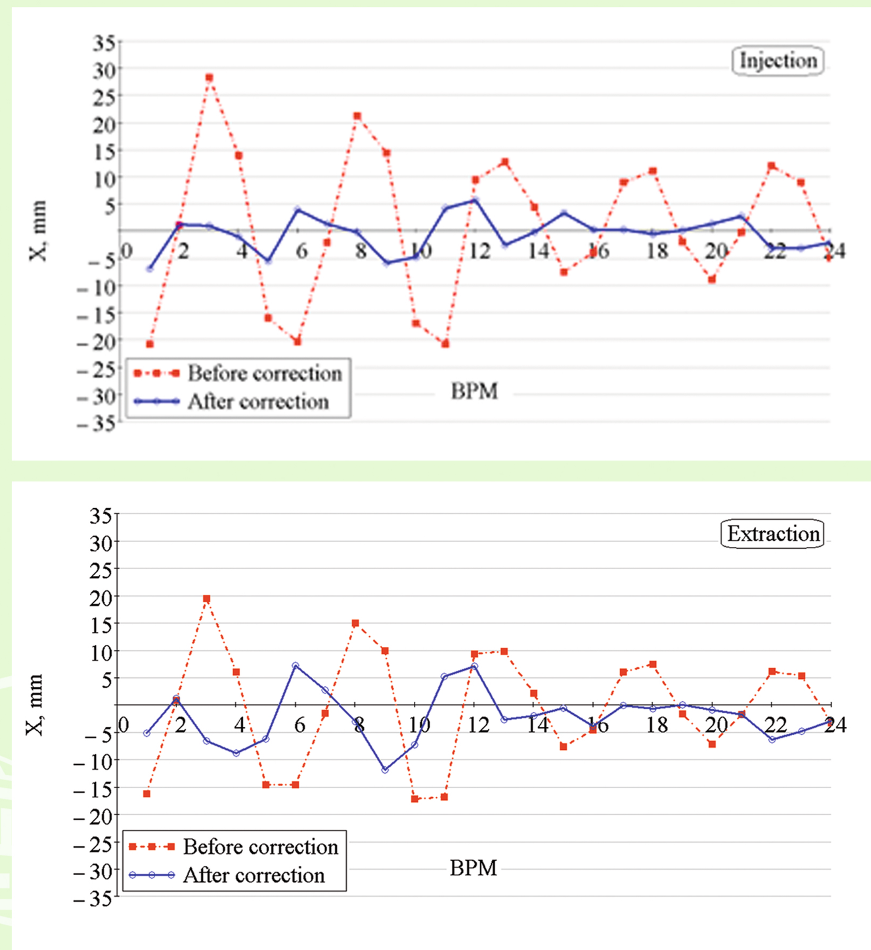

Figure 7: Measured results for beam obit correction in horizontal plane at injection (top) and extraction (bottom)

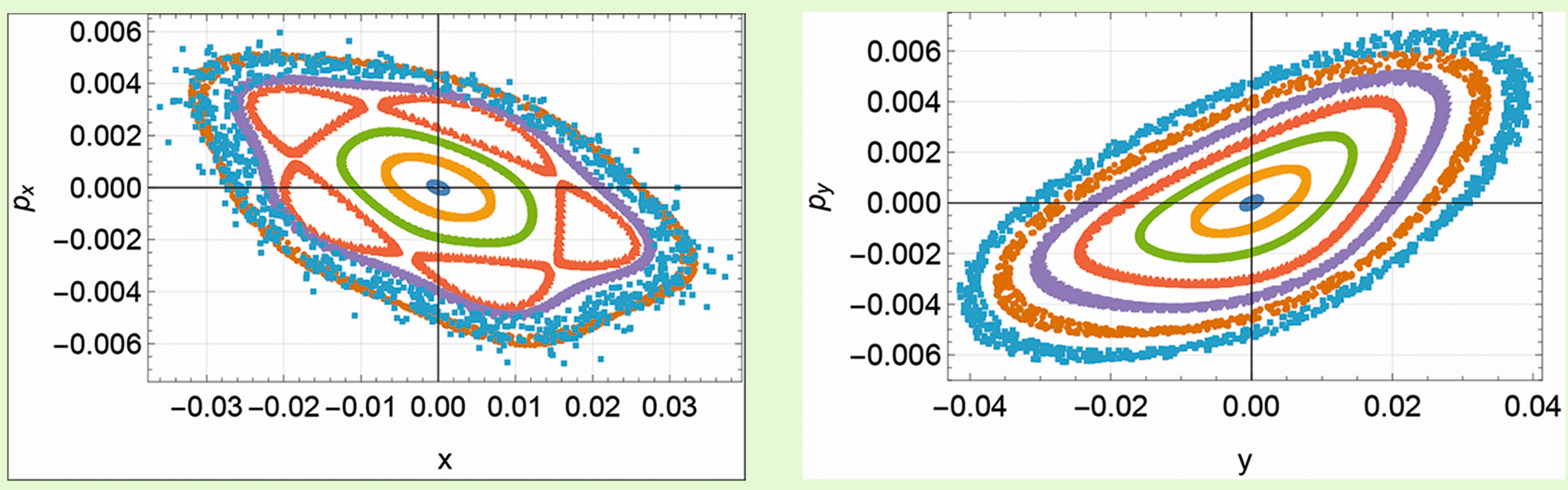

Figure 8: Phase portraits at the injection energy in the vicinity of the 5th (left) and 3rd (rigth) orderresonances

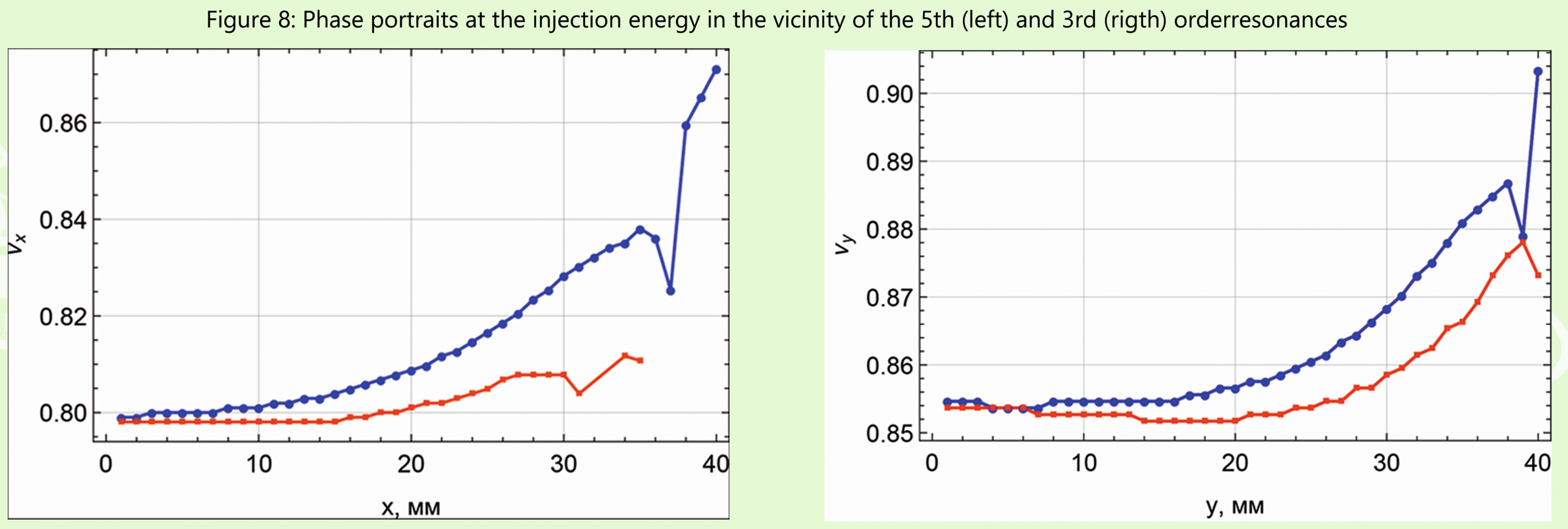

Figure 9: Tune vs.initial amplitude dependences when sextupole correctors are switched off (blue) and on (red) at the injection energy

CONCLUSION

The development and production of the Booster corrector magnets has been finiished at LHEP. The analytical and 2D FEM calculations were done in magnet center. In general, difference between analytical and FEM models less than 1% (except dipole coil) has been observed. The influence of the errors of the NICA Booster lattice elements on the transverse DA was carried out at the injection and extraction energies. For the DA simulations and error impact assessment a special technique has been developed. The DA was estimated in 2D and 4D phase space. The 2D DA in the horizontal and vertical phase planes exceeds the horizontal and vertical acceptance (at the injection energy by more than 2 times) were observed. The numerical analysis of fundamental frequency (NAFF) was used to obtain the tune vs. initial amplitude dependencies from the tracking results. The difference between calculations and measurements of the differential orbit less thsn 1% was found. In the experimental results, the closed orbit distortion less than 5mm (at the injection energy) and 12mm (at the extraction energy) after correction were observer.

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