MODIFICATED LATTICE OF THE COMPTON X-RAY SOURCE NESTOR *

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Abstract

NESTOR is Compton X-ray source that is under commissioning in NSC KIPT. One of the main parts of the facility is the middle energy storage ring (40-225 MeV). The storage ring has comprehensive lattice to provide low emittance, low beam size in the interaction point and big value of the energy acceptance. One of the NESTOR storage ring lattice feature is use of bending magnets of 0.5 m radius with combined focusing function. It leads to increasing of 3D magnetic field effects on electron beam dynamics.

After NESTOR magnetic element manufacturing characteristics of element magnetic fields were measured and the effect of the real magnetic field distribution on beam dynamics was calculated. As a result, to provide project X-ray source characteristics the parameters of NESTOR storage ring lattice should be modified. The second reason for the lattice modification was the desire to increase the interaction point straight section length.

The results of the beam dynamics simulation after lattice modification and optimization show that the storage ring will provide all project electron beam parameters. The results of the electron beam simulations are presented in the paper.

INTRODUCTION

In recent years a scheme of hard X-ray production using the laser electron interaction with relativistic electron beam circulating in compact storage ring is under design and development in NSC KIPT [1]. The background for the idea seems quite clear and efficient. It appears that for producing the X-ray beams with high intensity the increasing of the initial laser beam intensity will be enough. Abilities of the modern laser equipments with the laser flash energies up to 10 J allow the laser-electron storage rings (LESR) to have bright prospects.

However, the electron beam dynamics in the LESR under conditions of interaction with the dense photon beam is essentially different from that in a commonly used storage rings. Such differences originate from increasing of the quantum fluctuation effects and, hence, from increasing of the energy spread in the beam. It leads to the increasing of the chromatic aberrations effect onto the particle motion. This effect is so crucial that leads to the beam blow-up and, finally, to its loss. On the other hand, in the case of total suppression of the chromatic effects in the ring, the effect of laser cooling leads to the decreasing of transverse beam size, and intrabeam scattering has to be taken into account.

NESTOR DESIGN LATTICE

The proposed in NSC KIPT the compact storage ring lattice for the intensive X-ray source NESTOR [1] takes into account all mentioned above. This versatile lattice allows us to vary the momentum compaction factor α for different operation modes. Its layout is shown in Fig. 1.

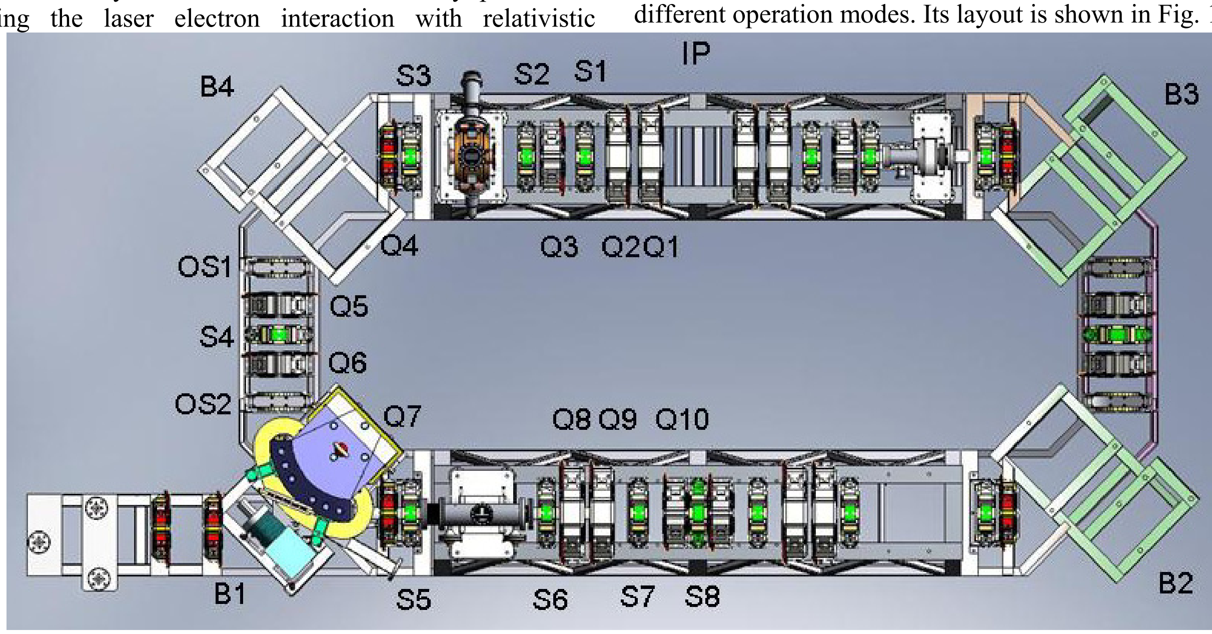

Figure 1: NESTOR X-ray source storage ring lattice layout. B1-B4 are dipole magnets with combined focusing function, Q1-Q10 are quadrupole magnets, S1-S7 are sextupole magnets, OS1-OS2 are octupole magnets combined with sextupole magnets.

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In the normal operation mode (N) the long straight sections B1-B2 and B3-B4 are dispersion-free. In the low α operation mode (LA) the dispersion function is negative along the part of beam trajectory in the dipoles B3 and B4, and the straight section B3-B4 acquires the non-zero dispersion while the straight section with IP is still achromatic in the first order. The momentum compaction factor in LA mode decreases of about factor 4 against that one in the N mode. It allows to ensure the energy acceptance of about 5 % for the electron beam energy E_0 = 225 MeV with the accelerating voltage V_0 = 0.5 MV. The required voltage can be provided by the single-cell 700 MHz cavity. In addition to the required energy acceptance providing function, the LA mode provides also the solution of the second LESR problem – to ensure the independence of the electron trajectory parameters on the particle energy at the IP.

4 90 degree bending magnets B1-B4 (Fig. 1) are used to form closed orbit. 20 quadrupole magnets are distributed along the storage ring design orbit and provide required beam betatron frequencies, beam sized along reference orbit and at the IP. Magnets Q5,Q6, Q15, Q16 provide dispersion conditions and correct momentum compuction factor α, triplets Q8-Q10 and Q11-Q13 along with triplets Q1-Q3 and Q18-Q20 form optical functions and betatron frequencies, Triplets Q1-Q3 and Q18-Q20 provide required beam sizes at IP. Quadrupoles Q4, Q7, Q14, Q17 match betafunction values of bending and long straight sections of the ring- To correct the chromatic effects 15 sextupole lenses S1-S15 and 4 combined octupole-sextupole magnets are placed along the orbit in The lattice has been designed to provide the required phase advances of betatron oscillations between sextupoles and to compensate the second order dispersion and the dependence of radial and vertical amplitude functions on the particle energy at the IP. The designed lattice has Q_x= 3.09307, Qz=2.16668 betatron frequencies and α=0.009608. Beta functions and dispersion function of the NESTOR storage ring lattice are shown in Fig. 2 and Fig. 3.

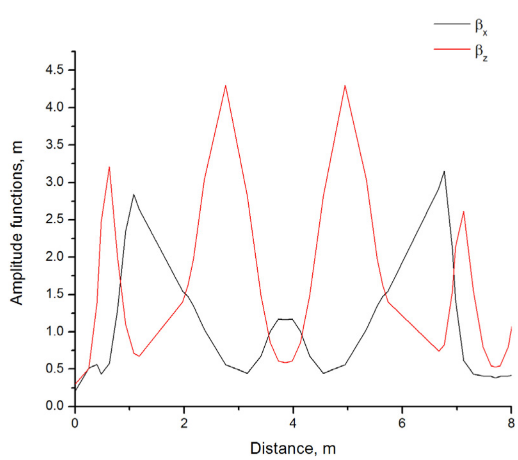

Figure 2: NESTOR X-ray source storage ring lattice beta functions.

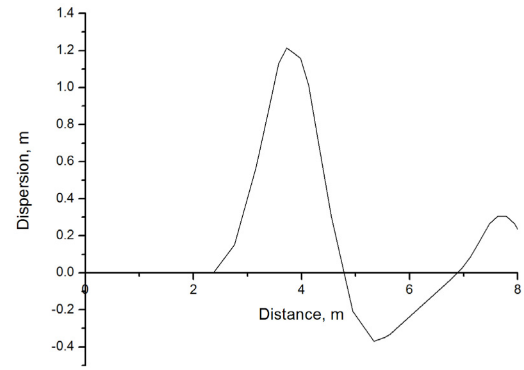

Figure 3: NESTOR X-ray source storage ring beta functions.

The feature of the NESTOR storage ring lattice is bending magnets with combined focusing function. To provide proper vertical focusing on the bending section of the ring the bending magnets with field index n=2.4 were used.

BENDING MAGNET PARAMETERS

The NESTOR storage ring bending magnets were manufactured and magnetic characteristics of the magnets were tested. Measurements of the storage ring dipole magnets have been carried out using the calibrated Hall probe array. Magnetic field characteristics one of the NESTOR magnet are shown in Fig. 4, 5. As one can see magnetic field in the magnet has uniform distribution and its value provides storage ring operation in energy range 40-200 MeV.

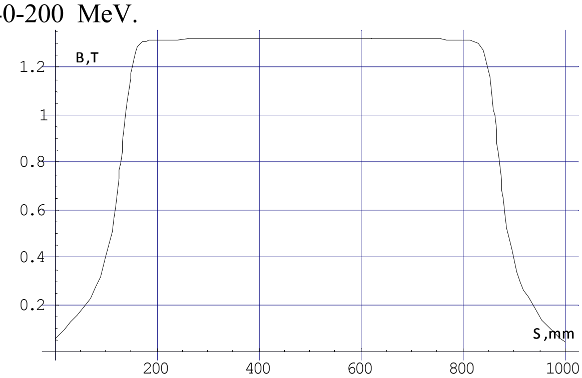

Figure 4 Longitudinal distribution of magnetic field along reference orbit (I_B=300 A).

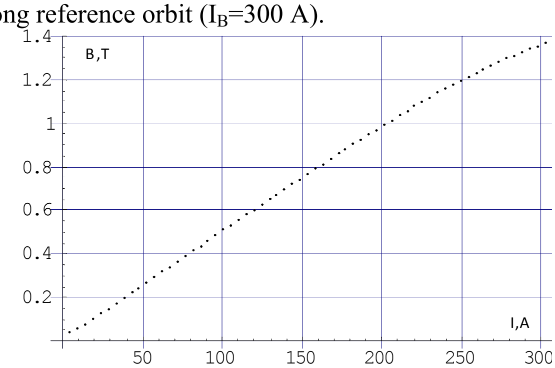

Figure 5: The magnetization curve of the first NESTOR storage ring bending magnet.

In Table 1 the angular effective length of the magnetic field and magnetic field gradient in NESTOR storage ring bending magnets are listed. The values of field index for each magnet are presented too. Unfortunately, one can see, that magnets have essential differences. Moreover, the effective length of the magnetic field is bigger then effective length of the magnetic field index. In addition, field indexes are different in each magnet and lower then it was supposed in design project. So, these facts will have essential effect on electron beam dynamics in NESTOR storage ring and stipulated new study of the lattice properties and its modification.

Table 1: Angular Effective Length of the NESTOR Bending Magnets

Magnetic field, T		B1	B2	B3	B4
O.41	B	89.57	89.63	89.68	89.66
	K1	87.32	86.79	87.41	87.66
0.95	B		89.60	89.60	89.61
	K1		86.93	87.40	87.31
1.33	B	89.38	89.39	89.37	89.39
	K1	88.48	87.75	88.34	88.03
	n	2.2	2.3	2.24	2.28

The another reason for NESTOR lattice modification is desire to increase the length of IP from 0.5 m to 0.75 m (Fig. 1) for more comfortable accommodation of optical resonator.

LATTICE MODIFICATION

As one can see from Tab. 1 NESTOR bending magnets not only have different characteristics but the force of vertical focusing is essentially lower then designed parameters. As calculations have shown the decreasing of vertical focusing leads to decreasing of vertical oscillation frequency to 2 and as a result the vertical motion in the ring is unstable. To improve the situation calculations and simulations were made with use of MAD [2] and DECA [3] codes.

At lattice modification the following factors were taken into account:

- IP should be increased to 0.75 m;
- The positions of all but IP triplet magnets should not be changed;
- The force of lenses could be changed within 20% from maximal magnet forces

As a result of calculations parameters of modified NESTOR storage ring lattice were determined. First the lattice parameters were determined in linear approximation. The lattice satisfied all requirements and in needed range of quadrupole magnet changes. In Fig. 6 the beta functions of modified lattice are shown.. It is clear that that theirs value is similar to the deign project beta functions (Fig/ 2). The betatron oscillation frequencies values are Q_x=3.101, Qz= 1.7859 and α= 0.00985. Second, the natural chromaticity was suppressed with sextupole magnets OS1-OS4 and S4-S12. Third. The dynamic aperture of the storage ring was corrected with sextupole magnets S1-S3, S17-S19. The value of the dynamic aperture at the injection point is about 42 mm in horizontal direction and about 26 in vertical direction. It is bigger then in design report and provides the effective injection in NESTOR storage ring.

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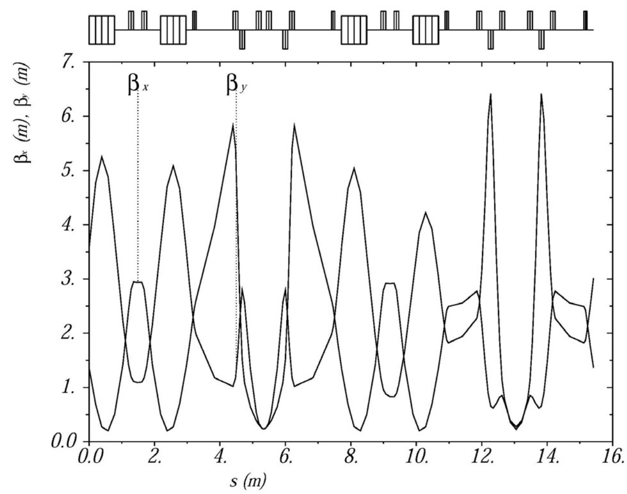

Figure 6: NESTOR X-ray source storage ring modified lattice beta functions.

So, NESTOR storage ring lattice has been modified successfully. The modification allows to compensate imperfection effects of the bending magnet manufacture and to increase the length of the IP straight section.

CONCLUSION

The modification of the NESTOR storage ring lattice allows to compensate imperfection effects of the bending magnet manufacture and to increase the length of the IP straight section with use of manufactured magnetic elements and to keep positions of the magnetic elements. It proves the correctness of chosen .design decisions and conceptual approaches to the LESR lattice design.

REFERENCES

[1] E. Bulyak, P. Gladkikh, I. Karnaukhov et al. Source of X-ray radiation based on Compton scattering // *Nucl. Instr. & Meth. In Phys. Res.* 2000, A 448, p. 48-50.

[2] H. Grote and F. Schmidt, MAD-X – AN UPGRADE FROM MAD8, Proceedings of the 2003 Particle Accelerator Conference, Portland, USA, May 12-16, 2003, pp. 3497-3499.

[3] P Gladkikh, M. Strelkov, A. Zelinsky. "The application package DECA for calculating cyclic accelerators". Proc. of the IIIth National Conf. on Particle Accelerator, 1993, p. 194-196.