NESTOR REFERENCE ORBIT CORRECTION

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Abstract

It is known that intensity of scattered radiation in X-ray generators based on Compton scattering strongly depends on relative position of electron and laser beams. For this reason it is very important to have effective system of reference orbit correction and beam position control as well along whole ring as at the interaction point.

In the paper the results of design and development of reference orbit correction system for compact storage ring NESTOR are presented. Correctors will be disposed at sextopole lenses and will provide reference orbit correction angle up to 0.1^0. The local correction at the interaction point will be provided with four correctors located at the interaction straight section. In the article results of calculations, layout of whole system, quadrupole lenses and pick-up station parameters and schemes are presented.

INTRODUCTION

Today, even with the modern technology one cannot manufacture two identical magnetic elements. Moreover, it is impossible to align magnetic elements of a ring lattice on the design orbit with absolute accuracy. Thus, imperfections of manufacturing and alignment of lattice element lead to parasitic dispersion appearance both in horizontal and vertical plane, to increasing of oscillation coupling and reference orbit displacement. As a result, reference orbit becomes non-planar. It leads to growth of vertical emittance and hence to the degradation of a source brightness. Besides, reference orbit displacement at the interaction point leads to mismatch of electron and laser beam position in X-ray sources based on Compton scattering. Therefore, intensity of scattered laser beam is decreased drastically. In addition, reference orbit displacement can lead to electron beam losses on walls of vacuum chamber. So, reference orbit correction is essential condition for proper operation of an X-ray generator based on Compton scattering in a storage ring. One of such facility is an X-ray generator NESTOR is under construction in NSC KIPT [1].

MISALIGNMENT EFFECT IN NESTOR STORAGE RING

Let us estimate how strong the effect of alignment errors is in a storage ring NESTOR. Calculations were done for the values of RMS displacement and tilt of lattice elements equal to Δx, Δz, $\Delta s = 1\times10^{-4}$ m, Δxz, Δzs, $\Delta sx = 2\times10^{-4}$ rad and Δx, Δz, $\Delta s = 5\times10^{-5}$ m, Δxz, Δzs, $\Delta sx = 1\times10^{-4}$ rad. Maximum reference orbit displacements without correction in horizontal plane is within boundaries $\Delta x_{max} = (1.44 – 2.92)\times10^{-3}$ m, and in vertical plane $\Delta z_{max} = (4.47 – 8.71)\times10^{-3}$ m. Taking into account that NESTOR vacuum chamber sizes are $x = \pm0.039$ m to horizontal and $z = \pm0.016$ m to vertical, an injection can be done without preliminary correction procedures. But the values of reference orbit displacements are big enough in both planes. These lead to essential increasing of an electron beam emittance, decreasing of the storage ring dynamic aperture and, therefore, decreasing of beam lifetime in the ring. Moreover, the values of RMS reference orbit displacement at the interaction point are in horizontal plane $\Delta x_{IP} = (1.27 – 7.8)\times10^{-4}$ m, and in vertical plane $\Delta z_{IP} = (4.63 – 9.41)\times10^{-4}$ m. Such values of electron and laser beam position mismatching essentially decrease effectiveness of the scattering process.

REFERENCE ORBIT CORRECTION

The correction of reference orbit position for storage ring NESTOR was carried out with method of eigenvectors [1]. The method can be characterized as one-step method of reference orbit correction. An algorithm using the method was realized in the code DECA [2] and good results were shown. Calculations were done for the following values of RMS displacements and tilts Δx, Δz, $\Delta s = 7.5\times10^{-5}$ m, Δxz, Δzs, $\Delta sx = 1.5\times10^{-4}$ rad. It was supposed that accuracy of the reference orbit position measurement is equal to 100 μ. The results of calculations are shown in Fig. 1. The maximum reference orbit displacement after correction in horizontal plane is $\Delta x_{max} = 2.41\times10^{-4}$ m and in vertical plane $\Delta z_{max} = 2.23\times10^{-4}$ m. Simultaneously, reference orbit displacement at the interaction point in horizontal plane is $\Delta x_{IP} = 5.2\times10^{-5}$ m and in vertical plane $\Delta z_{IP} = 6.4\times10^{-5}$ m. Such values of beam mismatching will essentially decrease an intensity of scattering process yet and for final beam position meeting the local correction of electron beam position is needed. Results of calculations are summarized in Table 1.

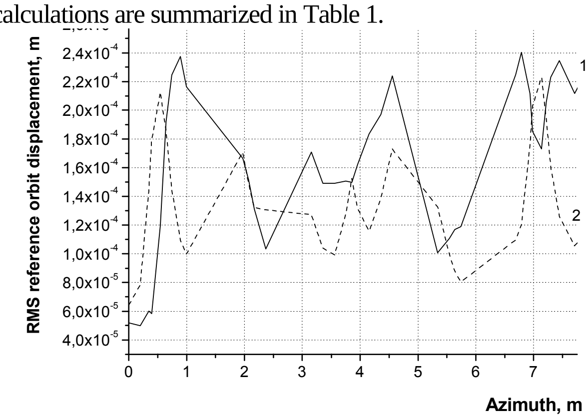

Figure 1. RMS value of reference orbit displacement along NESTOR orbit on a half of circumference.

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Table 1. RMS reference orbit displacement.

	Without correction		With correction	
	max	IP	max	IP
Horizontal plane, [mm]	1.44 – 2.92	0.127 – 0.78	0.241	0.052
Vertical plane, [mm]	4.47 – 8.71	0.463 – 0.94	0.223	0.064

At reference orbit correction procedure 12 pick-up monitors and 9 correctors were used. The layout of correction elements location along the ring orbit is depicted in Fig. 2. It is supposed that corrector magnets will be combined with sextupole magnets as it is shown in Fig. 3. The maximum values of corrector magnetic field are presented in Tables 2 and 3, whereas the sextupole magnet design allows to set coils providing field value up to 0.03 T.

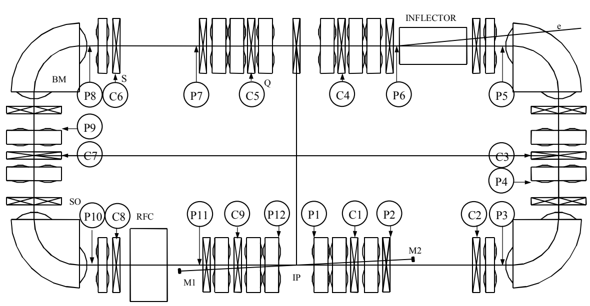

Figure 2. Layout of pick-up and corrector location along NESTOR orbit: P1-12 – pick-up monitors; C1-C9 – correctors in sextupole magnets.

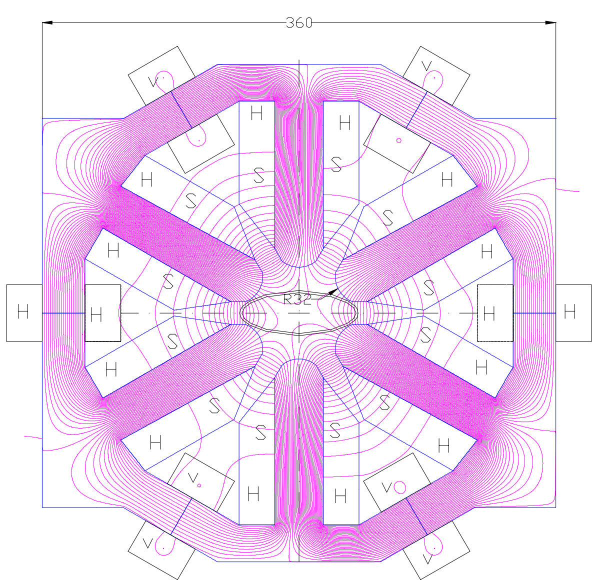

Figure 3. Layout of sextupole magnet with corrector coils.

For the reason of room lack along NESTOR ring pick-up monitors will be welded in vacuum chamber and set under quadrupole magnet coils as it is shown in Fig.4. Pick-ups position will be determined with quadrupole position along which it will be set. The pick-up monitor designed for NESTOR provides an accuracy of reference orbit coordinate approximation of about 10 μ [3]. So, summarizing measurement errors from pick-up alignment, coordinate approximation, electronic channel one can claim that pick-up monitors will provide an accuracy of reference orbit measurement of about 100 μ.

Table 2. Values of correction angles and values of magnetic field in correctors for vertical correction.

Element	RMS angle, deg	Min angle, deg	Max angle, deg	B_{xmax}, T
CZ1	0.03479	-0.107	0.112	0.0147
CZ2	0.02509	-0.079	0.071	0.0103
CZ3	0.03242	-0.112	0.102	0.0147
CZ4	0.0286	-0.072	0.085	0.0112
CZ5	0.02733	-0.074	0.077	0.0101
CZ6	0.01605	-0.045	0.053	0.0070
CZ7	0.02035	-0.062	0.059	0.0081
CZ8	0.01676	-0.044	0.045	0.0059
CZ9	0.03202	-0.086	0.107	0.0140

Table 3. Values of correction angles and values of magnetic field in correctors for horizontal correction.

Element	RMS angle, deg	Min angle, deg	Max angle, deg	B_{xmax}, T
CX1	0.03317	-0.102	0.101	0.0134
CX2	0.02465	-0.073	0.068	0.0096
CX3	0.02555	-0.09	0.073	0.0118
CX4	0.0372	-0.095	0.123	0.0161
CX5	0.03902	-0.131	0.104	0.0172
CX6	0.02547	-0.082	0.076	0.0108
CX7	0.02295	-0.097	0.064	0.0127
CX8	0.02725	-0.089	0.098	0.0163
CX9	0.03226	-0.116	0.087	0.0152

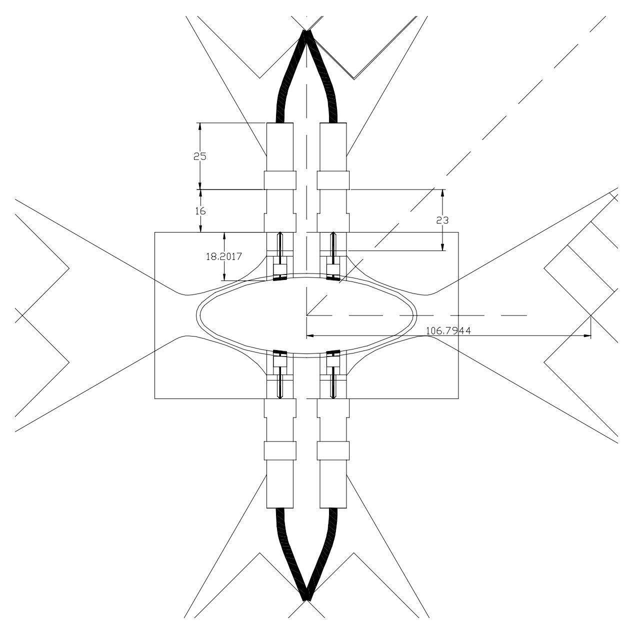

Figure 4. Layout of pick-up monitor installation in NESTOR.

LOCAL CORRECTION OF ELECTRON BEAM POSITION

As it was already noted above, the intensity of scattered radiation strongly depends on interacting beam position matching. Supposing Gausian distribution of particle density in the interacting beams, the dependence of scattered radiation intensity on mismatching value can be written as following:

$$N_\gamma = \frac{A_l A_x A_z}{2\pi\sqrt{\sigma_{R01}^2+\sigma_{z02}^2}} \frac{\sigma N_{01} N_{02} f}{\sqrt{\sigma_{x02}^2+\sigma_{R01}^2+\left(\sigma_{l01}^2+\sigma_{l02}^2\right)\tan^2\left(\frac{\alpha_0}{2}\right)}},$$

where

$$A_l = e^{-\frac{\Delta l^2 \tan^2\left(\frac{\alpha_0}{2}\right)}{2\left(\sigma_{x02}^2+\sigma_{R01}^2+\left(\sigma_{l01}^2+\sigma_{l02}^2\right)\tan^2\left(\frac{\alpha_0}{2}\right)\right)}},$$

$$A_x = e^{-\frac{\Delta x^2}{2\left(\sigma_{x02}^2+\sigma_{R01}^2+\left(\sigma_{l01}^2+\sigma_{l02}^2\right)\tan^2\left(\frac{\alpha_0}{2}\right)\right)}},\ A_Z = e^{-\frac{\Delta z^2}{2\left(\sigma_{R01}^2+\sigma_{z02}^2\right)}},$$

Δl and Δx, Δz are longitudinal, horizontal and vertical mismatching of center position of the interacting beams.

The dependence of intensity of scattered radiation on mismatching value is shown in Fig. 5. The calculations were carried out for electron beam with current equal to 0.01 A and electron energy equal to 43 MeV. The beam sizes were σ_x=300 μ, σ_z=80 μ, σ_s = 3000 μ. These values correspond to steady state electron beam sizes after 2000000 turns simulation taking into account intrabeam scattering and interaction with Nd:YAG laser flash with laser beam energy equal to 0.001 J under interaction angle 0.05 rad. The laser beam sizes were equal to σ_x=σ_z=50 μ, σ_s = 1000 μ. As it is clear from the figure, under such conditions of interaction and values of beam position mismatching after global correction procedure the intensity of scattered radiation is decreased as much as 1.5 times.

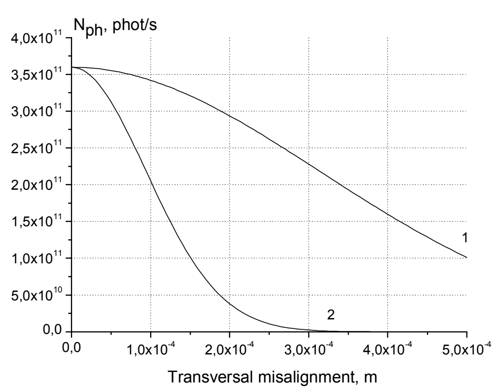

Figure 5. Scattered radiation intensity vs transversal mismatching of electron and laser beam position. 1 - mismatching in horizontal plane; 2 - mismatching in vertical plane.

To correct this situation it is supposed to make local correction of electron beam position at the interaction point using four correctors C1, C2, C8, C9 (Fig. 2). Controlling field in correcting coils of these correctors one can displace reference orbit position at the interaction point. Reference orbit coordinate out of correcting region will still stay the same. Scanning with an electron beam area around design orbit the beam position matching will be reached considering maximum value of intensity of the scattered radiation.

Using matrix formalism forces of C1, C2 correctors for interaction straight section of NESTOR lattice were derived:

$$h_{1x}[T] = 30.1584 \times x[m],\ h_{1z}[T] = -7.18311 \times z[m],$$

$$h_{2x}[T] = 11.8432 \times x[m],\ h_{2z}[T] = 7.89295 \times z[m],$$

where x and z are values of reference orbit displacement one needs.

For returning of reference orbit position to original unperturbed condition it is necessary to specify the following forces of the correctors C9=C1, C8=C2.

In Fig. 6 the reference orbit trajectories along the lattice section IP-C2 under reference orbit displacement at the PI equal to x=z=500 μ are shown.

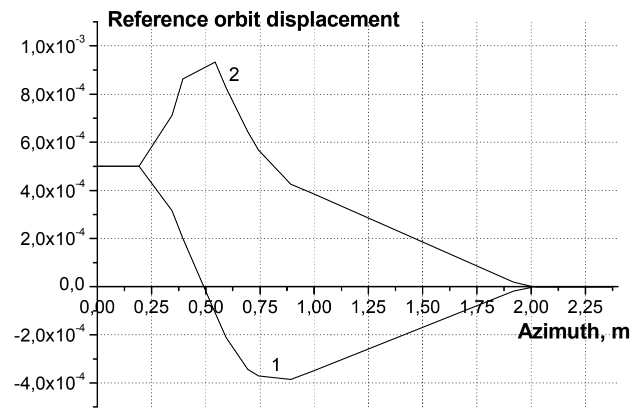

Figure 6. Reference orbit displacement for compensation of lattice element alignment effect vs NESTOR azimuth from the IP till the first bending magnet enter: 1 - in horizontal plane, 2 - in vertical plane.

CONCLUSION

Designed in NSC KIPT reference orbit correction system provides high-grade electron beam position correction along whole NESTOR storage ring orbit and provides conditions for long-term X-ray generation without decreasing of generated radiation intensity due to electron beam misalignment effects.

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