THE DYNAMICAL APERTURE OF ISI - 800

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Beam dynamics studies of the ISI-800 electron storage ring are described in the normal operation mode, the operation mode with a wiggler and the modified lattice with a superconducting magnet. A study of the effects of resonances included by sextupoles and optimization of dynamical aperture is carried out. The effects of magmetic multipole errors, alignment and excitation errors are discussed.

1. ISI-800 LATTICE CHARACTERISTICS

The Ukrainian Synchrotron Light Source ISI-800 is desiged as a dedicated vacuum ultraviolet - soft x-ray radiation source. The photon beams will be provided by bending magnets and insertion devices (wigglers, undulators).

The lattice ISI-800 is a four-fold symmetric three-bend achromat lattice operating with 800MeV electrons [1]. Three-meter of long dispersion-free straight sections are provided for insertion devices.

Figure 1 shows the optical function for the normal operation mode in the superperiod of the ring. Figure 2 shows the optical functions for the operation mode with a wiggler magnet (H_{max}~ 10T) in the dispersion-free straight section. In th-s operation mode the optical functions are the same as in the normal operation mode, except for the straight section with a wiggler. The harmony of optical functions is ensured by two quadrupole triplets in addition. The latest lattice version of ISI-800 is a modified lattice of four-fold three-bend achromat, where the central magnet is superconducting with H~10T [2]. Figure 3 shows the optical functions for the modified lattice.

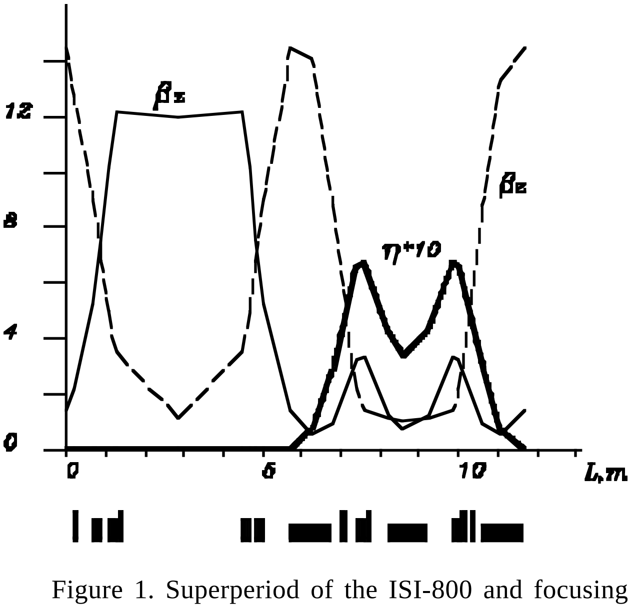

Figure 1. Superperiod of the ISI-800 and focusing function for the normal operation mode. The linear horizontal and vertical tunes are ν_x=4.24, ν_z=3.16.

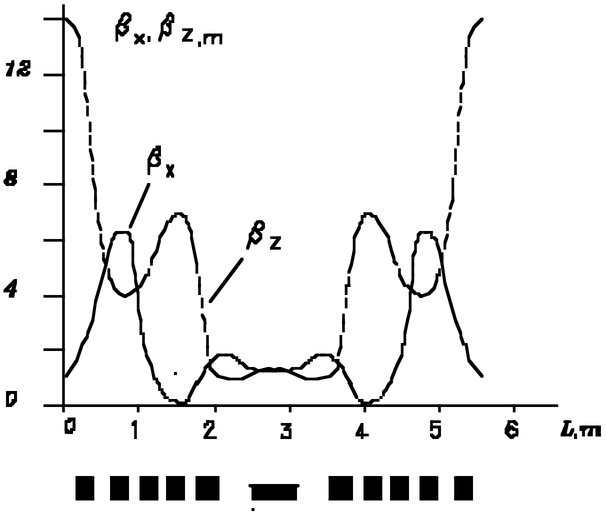

Figure 2. Focusing functions in the straight section with a wiggler. ν_x=5.26, ν_z=3.18.

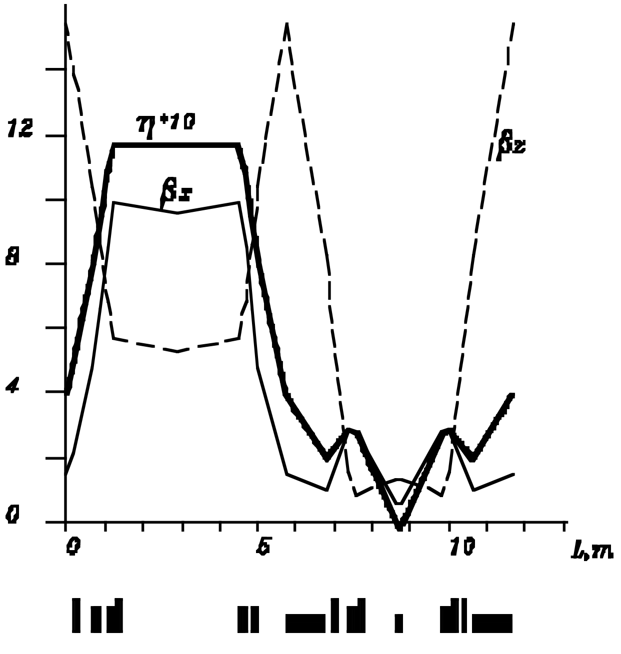

Figure 3. The focusing functions of one superperiod of modified lattice ISI-800 for the operation mode with minimum emittance. ν_x=4.3, ν_z=3.2.

2. RESULTS OF THE ISI-800 DYNAMICAL APERTURE CALCULATION

The dedicated storage ring must be optimized for a small beam emittance. This had lead us to the use of strong focusing lattices, which produce large chromatic aberrations. The natural chromaticity $\varepsilon_0\nu/(\Delta p/p)$ (ε_{0x}= -7.6, ε_{0z}=6.9 for ISI-800 normal operation mode; ε_{0x}= -8.9, ε_{0z}= -10.15 for operation mode with a wiggler;ε_{0x}= -6.2, ε_{0z}= -6.6 for operation mode with a modified lattice) must be compensated. Two families of chromaticity correcting sextupoles are introduced in the dispersive straight sections of the ring. These sextupoles, however, introduce non-linear perturbations which limit the dynamical aperture of the ring.

We try to minimize the effects of these chromaticity correcting sextupoles by introducing two other sextupole families located in the non-dispersive straight section. The theoretical optimization of the sextupoles located in the non-dispersive straight section is based, on the one hand, on the analytically determinated region of stability due to the joint action of the first-and third-order resonances perturbed by sextupole fields [3] for ν_x~4; $3\nu_x$~12 and, on the other hand, on the minimization of the tune shift with amplitude.

In the case where the linear tune is far from resonances, we have:

$$\Delta\nu_x=AJ_x+BJ_z;\ \Delta\nu_z BJ_x+CJ_z\ ,$$

where $\Delta\nu_x$ and $\Delta\nu_z$ are the horizontal and vertical tune shifts; A,B,C are the coefficients determined by the lattice only (they are, thus, dependent on sextupole configuration), and J_x, J_z are the action variables which are the constants of motion and depend on the initial conditions of the particle. The calculations of the tune shift with amplitude are done by the code DeCA [4]. The sextupoles are considered as thin lenses. Figures 4, 5, 6 shows the dynamical aperture analytic calculations based on the joint action of the first-and third-order resonances and the tune shift depending on amplitude [3]. (curves 1).

Table 1 lists the values for the coefficients of the tune shift depending on amplitude for the normal operation mode (N), the operation mode with a wiggler (W) and the operation mode of the modified lattice (M).

Table 1.

	N	W	M
A, m^{-1}	-165	21	-122
B, m^{-1}	-321	721	-5
C, m^{-1}	-133	50	-157

For comparison we give the dynamical aperture values calculated at the same conditions by the code DeCA [4] (200 particles, 50 turns) - curves 2. The approach described above considers the effects of sextupoles on the lattice only. To take into consideration other effects such as higher-order multipole errors, excitation and alignment errors numerical tracing simulation is performed with DeCA. The final choice of the sextupole strengths is based on the results of computer simulation.

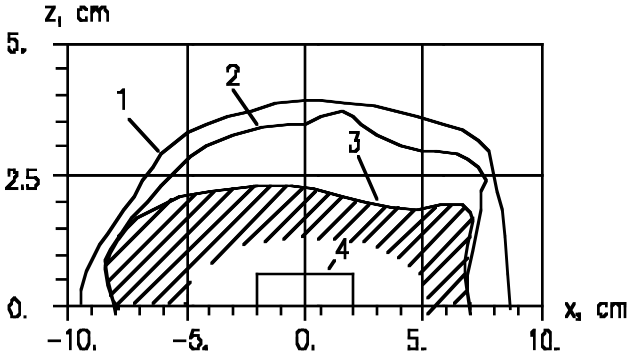

Figure 4. Dynamical aperture in the middle of the insertion straight section for the normal operation mode. 1- Analytical calculations of dynamucal aperture with consideration of the combined action of first-and second-order resonances and the tune shift depending on amplitude. 2- Dynamical aperture obtained by numerical calculations (200 particles, 50 turns) if only regular sextupoles exist. 3- Dynamical aperture obtained by numerical calculations if systematic multipole errors are occur. 4- Geometrical aperture in the middle the straight section. The hatched region corresponds uncertainly region of dynamical aperture.

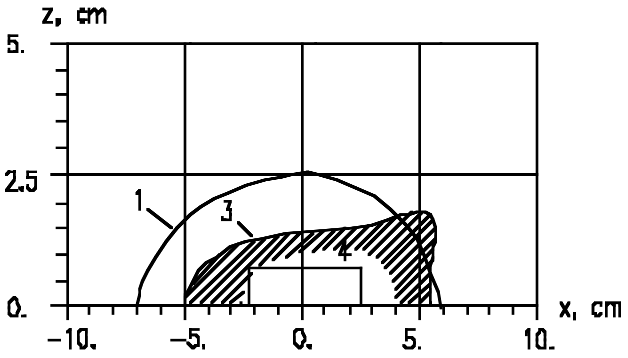

Figure. 5. Dynamical aperture in the middle of the insertion straight section for the operation mode with a wiggler.

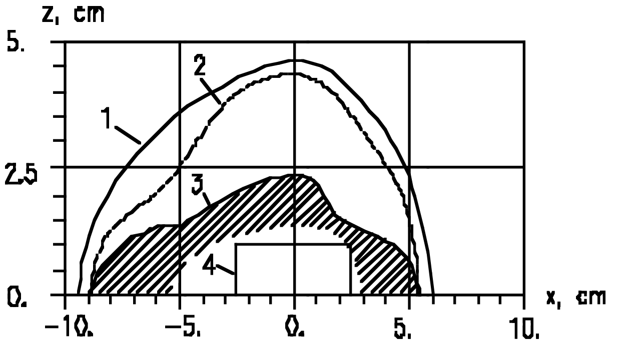

Figure 6. Dynamical aperture in the middle of the insertion straight section for the modified lattice.

The multipole errors are the higher-order terms of the real magnetic field expansion. Multipole errors fall into two categories: systematic and random multipole errors. The systematic errors are those caused by the finite dimensions of the poles and the same for each magnet of the same kind, whereas the random errors arise because of constructional tolerances and are different for each magnet.

Analysis of systematic errors shows that the influence of sextupole and octupole components of dipole magnetic fields is of most vital importance. Sextupole components were determined by calculating the using the Poisson equation. The octupole component of the dipole magnetic field is connected with fringing fields and is determined by the method offered in [5].

Table 2 shows the systematic multipole errors included for simulation (l_m - length of element).

Table 2.

	Normal dipole	Super - conducting dipole	Wiggler
$\frac{\partial^2 H_z}{\partial x^2} l_m$, T/m	4	40	3
$\frac{\partial^3 H_x}{\partial z^3} l_m$, , T/m^2	100	1000	1600

Figures 4, 5, 6 shows the dynamical aperture (curves 3), which was obtained with the DeCA (200 particles, 50 turns) attached to systematic errors. These errors lead to the decrease of the dynamical aperture in vertical. Systematic quadratic nonlinearities are compensated by correcting sextupoles.

After determining the dynamical aperture with systematic multipoles included errors of a simulation involving random multipole errors (table 3) plus distortion of the closed orbit (Δx, Δz) with one standard deviation Δx, Δz ~2mm was performed.

Table 3.

Multipoles	One standard deviation
$\frac{\partial^2 H}{\partial x^2} l_m$, T/m	3
$\frac{\partial^3 H}{\partial x^3} l_m$, T/m^2	100
$\frac{\partial^4 H}{\partial x^4} l_m$, T/m^3	5000

Particles are tracked using code DeCA for 200 particles and 200 turns. Results for the dynamical aperture calculations in the middle of the long insertion straight section are shown in figures 4, 5, 6. The hatched regions in these figures correspond to the uncertain region of dynamical aperture for three different sets of random errors and closed orbit used.

3. CONCLUSIONS

The dynamical aperture of the ISI-800 storage ring for the normal operation mode, the operation mode with a wiggler and the operation mode of a modified lattice has been optimized using two families of sextupoles in the nondispersive straight section using Hamiltonian formalism. These calculations are used to obtain the first estimate to the values of the correcting sextupoles.

The optimum set of values is found by numerical tracking including higher-order systematic multipoles which are not taken into account in the previous formalism. We have found for ISI-800, that even if other random errors are included, the dynamical aperture remains sufficiently large.

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