PROGRESS OF THE ISI-800 PROJECT

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ABSTRACT

The general layout of ISI-800, a low emittance third generation machine consisting of a linac injector (120 MeV), a storage ring with 4-period TBA lattice, and intended for research and industrial applications, is presented together with a discussion of most important design considerations. Design features of magnet, vacuum, injection RF systems are described. Three straight sections are available for wigglers and undulators, and up to 24 photon beam lines may ultimately emanate from dipole magnets. The emittance is 27 nm. The dynamic aperture is sufficiently large for the injection and the stable storage of the beam.

INTRODUCTION

The use of synchrotron radiation noted for its broad continuous and high brightness has brought the research in the fields of molecular physics, physics of condensed states of matter, chemistry, microbiology, etc. to a qualitatively higher level. In recent years, great interest has been displayed in basic synchrotron radiation sources whose physical properties along with performance parameters provide a means for handling process problems of X-ray lithography in microelectronics (photon energy ε_γ ~ 1 keV), micromechanics (ε_γ ~ 6 keV) and angiography (ε_γ~ 33 keV). The design of a relatively cheap and compact source with the above-mentioned photon beam parameters is a complicated task, since the compactness of the source sets limits, first of all, on the electron energy, and hence, on the energy of emitted photons. This, in turn, necessitates the mounting, arrangement of special devices such as superconducting wigglers with limiting magnetic-field values of about 10 T. However, the installation of such wigglers in the storage rings with a beam energy lower than 1 Gev is impeded by an impact of magnets on the beam focusing and phase stability of the orbit in the storage ring. This makes necessary long straight sections in the lattice to accommodate the matching elements, and also imposes special requirements on the wiggler design. Furthermore, in consequence of a great distortion of the reference orbit in the wiggler (Δx ~ 5 cm at an electron energy of 0.8 GeV and a field of 10 T in the wiggler), there arise essential technological difficulties. This paper describes the concept of a SR source which can form the basis of creating the National Centre of SR [1]. Ways of realizing this concept are discussed.

MAIN STORAGE RING PARAMETERS

The upper limit of the magnetic-field strength range, at which the magnetic materials can ensure a high-quality field, is about 1.5T. Besides the radiation from bending magnets, the modern SR sources incorporate superconducting wigglers (with the field up to 10 T) to increase the energy of the photons produced. The electron beam energy of about 1 GeV allows the generation of photon beams complying with the requirements of most applications.

We came to conclusion that SR source would be a 1 GeV compact electron storage ring. Injecting energy was chosen to be 120 MeV. The traveling wave linac is intended to employ as an injector. The injector is placed below the ring to provide room for more beamlines. For this purpose the injecting system and the RF cavity share the same long straight section. The general layout of the complex is presented in Fig. 1.

The magnet lattice is responsible for both the efficient operation of the source and the SR beam quality. One of the principal SR beam parameters, i.e., brightness, is proportional to the transverse electron-beam density in the region of radiation. Therefore, it is necessary to have a beam with a minimal cross-sectional area; the lattice must ensure the minimal beam emittance and a low value of the vertical betatron function in bending magnets. The latter allows one to diminish the magnet gap, thereby reducing the cost of magnet manufacture and operation.

We have chosen the TBA lattice as providing low emittance. It consists of four superperiods. The structural formula of each superperiod has the form

$$O_1\ QD\ O_2\ QF_1\ O_3\ QF_1\ O_2\ QD\ O_1\ M\ O_4\ QF_2\ O_4\ M\ O_4\ QF_2\ O_4\ M$$

where QD, QF_i are the horizontally defocusing and focusing quadrupoles; M is the dipole magnet, O_i is the straight section; O_1=0.7 m; O_2=0.15 m; O_3=3.23 m; O_4=0.6 m.

The curvilinear part of the trajectory includes: 3 magnets, each with a bending angle of 30°, the curvature radius R=2.005 m (B=1.34 T at an electron energy E=0.8 GeV, B is the magnetic field strength at the equilibrium orbit), the field

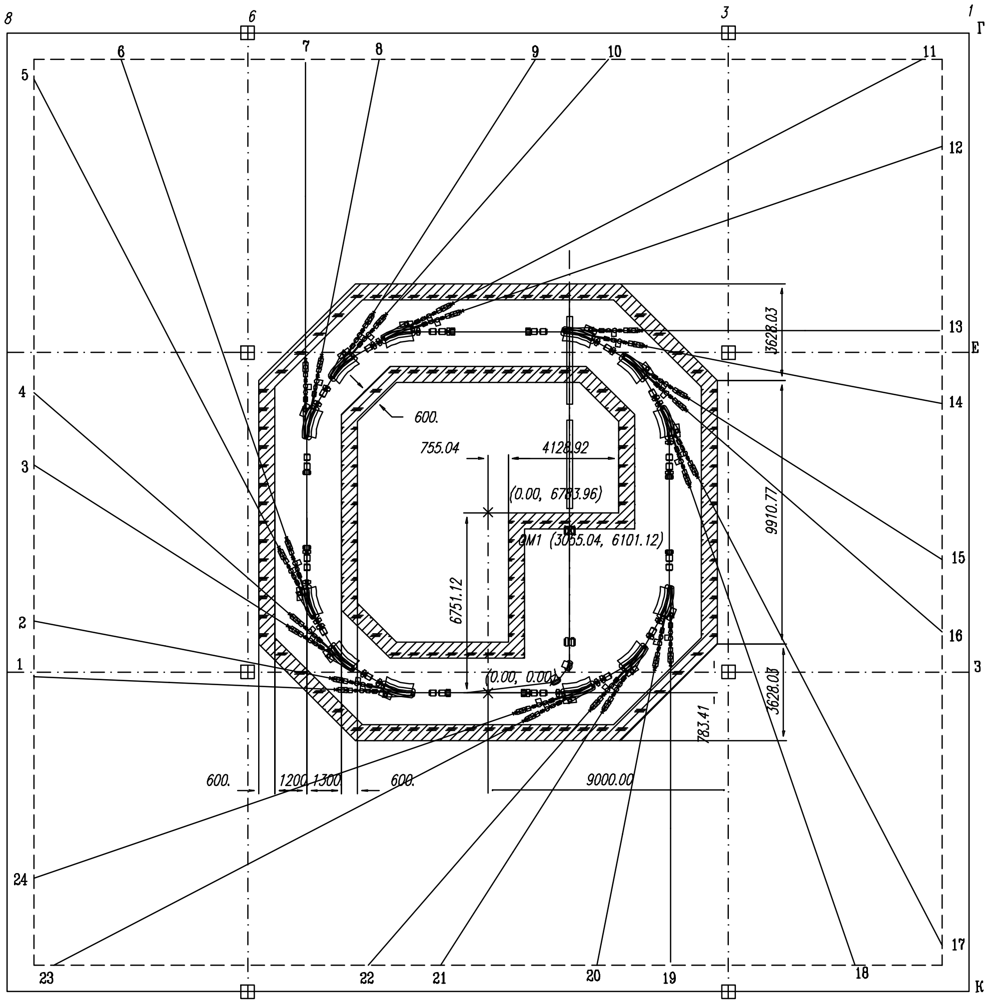

Fig.1. The general layout of the ISI-800

index *n*=3 and 2 focusing quadrupoles providing the achromaticity of the long straight part of the orbit.

The straight-line part of the trajectory comprises four quadrupole magnets which ensure the stability of radial and vertical motion in combination with two quadrupole magnets and vertically defocusing dipole magnets. Fig. 2 shows the machine functions of the superperiod for the zero dispersion function in the long straight section.

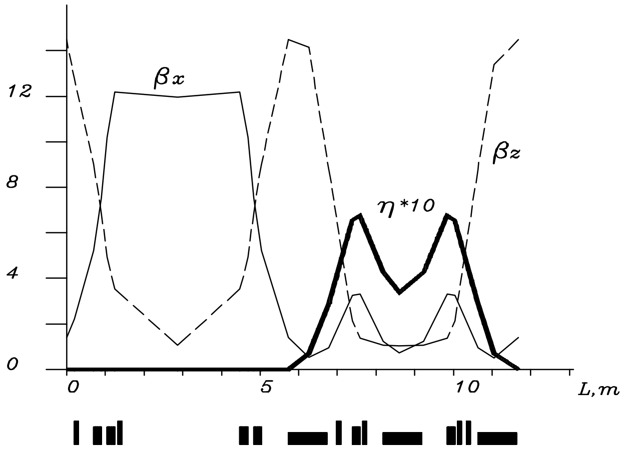

Fig. 2. The machine functions of a superperiod.

The phase advance for the focusing period is $\mu_x = 6.666$ and $\mu_z = 5.026$ for radial and vertical oscillations, respectively. These values correspond to the tunes $Q_x = 4.25$ and $Q_z = 3.20$. Since the vertical focusing is mainly accomplished by gradient dipole magnets, this provides the smallest value of the betatron radial function β_x in the

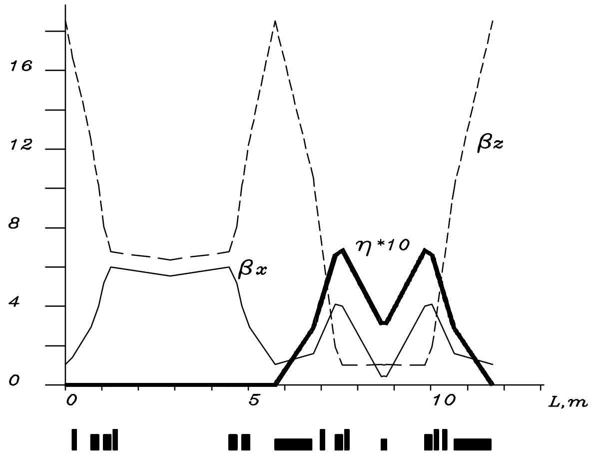

Fig.3 Machine functions of the modified TBA cell.

magnet, and hence, the minimum radial size of the beam. The radiation emittance is $\varepsilon_x=2.7\cdot10^{-8}$ mrad (E=0.8 GeV) for the steady-state energy straggling $\Delta p/p=5.88\cdot10^{-4}$ (E=0.8 GeV).

The operating conditions of the SR source are characterized by a low radiation emittance attained due to a higher rigidity of the magnet lattice. This has resulted in the increased natural chromaticity, the compensation of which requires the mounting of sextupole lenses arranged in the sections with a nonzero dispersion. At large betatron amplitudes the presence of sextupole fields leads to the occurrence of undesirable nonlinear effects, which significantly decrease the dynamic aperture. The simulation has resulted in the following conclusions:

- the inclusion of sextupole lenses to correct the dynamic aperture appreciably increases the latter both in the absence and presence of sextupole perturbations in the dipole magnet;
- with the corrected equilibrium orbit and the compensation lenses switched on the dynamic aperture exceeds the geometric one, and therefore, will not affect the beam parameters.

The dynamical aperture values calculated at the same conditions by the code DeCA [3] (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.

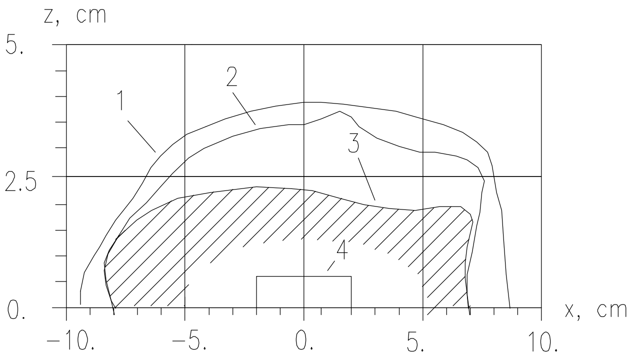

Figure 4. Dynamical aperture in the middle of the insertion straight section for the normal operation mode. 1- Analytical calculations of dynamucal aperture with consideration of the combined action of first-and second-order resonances and the tune shift depending on amplitude. 2- Dynamical aperture 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.

The multiple injection chosen for this design consists in the following. The beam from the injector is horizontally introduced, via the transport system, to the vacuum chamber of the ring, where it is bent by the necessary angle with the help of the septum magnet. By the moment of injection of the next beam portion the orbit of the ring in the region of injection comes closer to the septum. After trapping the necessary number of turns, the orbit is restored, the initial betatron oscillations are damped.

To produce high-brightness photon beams with a sufficiently high energy, we also considered a compact storage ring with the lattice based on the combined TBA cell ("warm" and superconducting magnets), where the central dipole magnet of the cell is superconducting.

The contribution of the central superconducting magnet (field is 10 T) to the emittance value at a beam energy of 0.8 GeV is $\varepsilon_x=2\cdot10^{-8}$ mrad.

Fig. 3 shows the machine functions for the the modified TBA cell of the ISI-800 storage ring. For comparison, Table 1 lists the values of the parameters for different variants of the ISI-800 storage ring lattice.

Table 1

Parameters of the ISI-800 storage ring

Parameter	TBA	Mod TBA
Nominal energy, MeV	800	800
Stored current, mA	200	200
Circumference, m	46.729	46.815
Number of dipole magnets	12	8+4
Radius of magnet bend, m	2.005	2.005/0.27
Magnet length, m	1.05	1.05/0.14
Betatron numbers, ν_x/ν_z	4.26/3.20	4.26/3.20
Compaction factor, α	0.025	0.021
Nat chromaticity, ξ_x/ξ_z	-7.27/-7.24	-6.2/-6.7
Damping times $\tau_x/\tau_z/\tau_s$,	8.7/13.8/9.8	8.4/9.9/5.4
Emittance, mrad	$2.7\cdot10^{-8}$	$4.\cdot10^{-8}$
Beam size in centre of SC		0.15/0.07
Energy spread, %	0.058	0.125
Losses per turn, keV	18.3	57.4
Crit. energy SC, keV		4.2

The simulation of the dynamic aperture of the storage ring with a modified lattice shows that the presence of the superconducting central magnet in the TBA lattice exerts no essential influence on the aperture value.

The synchrotron light generated by the electron beam with current up to 200 mA and the radiation emittance of $2.7\cdot10^{-8}$ m·rad would be utilized by beam lines. Each line will provide the light beam with spectral brightness of $(2\text{-}9)\cdot10^{20}$ phot /($m^2\cdot rad^2$) within 0.01% bandwidth. We have designed the general purpose beamline. This project allows one to assemble dedicated beamline (for, e.g., photolithography, EXAFS, x-ray material analysis, etc.). The radiation from both conventional magnet dipoles and wigglers as well would be utilized through this line.

The beamline is supposed to operate in following modes:

1. X-ray lithography beamline (comprises from no optical elements inside). Transverse beam dimensions could be achieved within the range of 0-30 mm.

2. The line with the turnable flat grid will be applied for experiments in physics and chemistry. This line comprised few optical elements covers photon frequency from VUV to the soft x-ray.

3 The toroidal grid monochromator line will be used in experiments requiring large photon flux and moderate resolution.

4. X-ray transmitting microscope.

5. The coronal angyography line.

The dipole magnet will have a conventional C type cross section. The rectangular magnet will be laminated, the laminates are 1.5 mm thick. The good-field region extends to ± 15 mm horizontally. The dipole parameters are given in Table 2.

Table 2

Parameters of dipole magnet

Number of dipoles	12
Length, m	1.05
Field strength (E=800 MeV), T	1.34
Horizontal good field, mm	30
Vertical good field, mm	20
Field index	3
Gap, mm	36
Pole width, mm	110
Number of turns in the winding	48
Cond cross section (12.5*12.5∅7.5), mm^2	99.5
Exciting current range, kA	0.16÷1.1
Magnet weight, kG	2000

24 quadrupole magnets are grouped in three families with 8 in each, the lenses in a family being connected in series. The poles of all the lenses are of one and the same profile The bore diameter is 50 mm and length is 20 cm for all quadrupole magnets.

The ISI-800 magnet lattice contains 4 families of sextupoles, total 24 magnets. To compensate the negative chromaticity $\xi_{x,z}$, which is equal to -7.14, -7.36, four sextupole magnets are mounted at the curvilinear part of the trajectory of each superperiod and two sextupole magnets in the achromatic part of each superperiod correct the dynamic aperture. The aperture radius of sextupoles is 28 mm, with a pole width of 28 mm. The magnets are capable of producting a field of 200 T/m^2 over a length of 0.1 m. The sextupole weight is 70 kG. In addition to the main coils mounted on the poles, there are six back-leg coils which, given the correct excitation, can generate vertical and horizontal dipole fields with maximum corrector strength: vertical 3 mTm, horizontal 3 mTm.

The synchrotron radiation facility ISI-800 will have a transfer line which has been designed for transporting 120 MeV electrons from the linac to the storage ring. The transfer line includes 4 dipole magnets (rectangular, C-type, bend angle is 41.5 degrees, length is 29 cm), 9 quadrupole magnets (length is 10 cm, gradient is 15 T/m) and 4 bidirectional steering magnets.

Correction of the storage ring orbit is accomplished by 8 horizontal, 8 vertical sextupole steering elements (combined with the sextupoles) in the curvilinear part of the orbit and 8 bidirectional dipole steering magnets distributed in the straight sections (length is 10 cm, field is 0.03 T).

Beam energy losses by synchrotron radiation and parasitic losses in the vacuum chamber walls are compensated with the help of a 10 kW RF (699.3 MHz) system. The accelerating voltage of 200 kV chosen in view of the Touschek lifetime, is provided by a single half-wave cavity, whose shape has been optimized against the shunt resistance at the main (operating) mode (Ω-cavity). As calculations and measurements indicate, this cavity has lower coupling impedances at higher-order modes than the cylindrical cavity has and, therefore, is less sensitive to the excitation of coupled oscillations of bunches.

Based on the reasonable 6-hour life of the zero-intensity beam we come to the conclusion that the residual gas pressure in the chamber should not exceed $5\cdot10^{-9}$ Torr throughout the range of circulating currents at an operating energy of the beam. Pumping is produced by 40 sputtering 400 l/s pumps placed on the dipole magnet chambers and by the end of the defocusing quadrupole magnets.

Sixteen pickup stations and a current transformer are used to monitoring the beam in the storage ring.

CONCLUSION

The design of the magnet, the vacuum, the RF and the indicating systems is completed. Also we have the project of the injector and the building.

Now we work on the modified TBA lattice, the beamlines, the design of the superconducting dipole magnet and the wiggler.

We have got the goverment decision about the construction of the synchrotron radiation source ISI-800 for Ukrainian National Synchrotron Center.

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