A COMBINED MAGNET LATTICE OF THE SYNCHROTRON LIGHT SOURCE ISI-800

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ABSTRACT

The design of an electron storage ring for low emittance mode operation is presented. The parameter optimization is based on the spectrum and on beam source sizes and on general specifications for the machine performance such as dynamic aperture, lifetime. Superconducting magnets in the middle of a TBA cell with a high field are used in the storage ring.

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_C~1 keV), micromechanics (ε_C~ 6 keV) and angiography (ε_C~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.

One of the ways out of this situation might be the construction of a compact synchrotron radiation (E ~ 1GeV) source with a photon energy up to 33 keV using the storage ring lattice with superconducting magnets as a basis. However, in such a lattice, owing to great beam energy losses by synchrotron radiation, a demand for a powerful RF system arises. Besides, a low emittance (ε_X~10 nm) in the lattice can be provided through a significant increase in the rigidity of the magnet lattice. As a consequence, the natural chromaticity of the ring will increase, and this will result in the reduction of both the dynamic aperture and the beam lifetime [1].

To produce high-brightness photon beams with a sufficiently high energy, it may be reasonable to construct a compact storage ring with the lattice based on the combined TBA (Three Bend Achromat) cell ("warm" and superconducting magnets), where the central dipole magnet of the cell is superconducting.

The minimal emittance in this lattice is given by the formula

$$\varepsilon^*_{x\,TBA} = \frac{55}{32\sqrt{3}}\frac{h}{2\pi m_e c}\frac{\gamma^2}{J_x}\frac{\dfrac{I_c}{\rho_c^3}+\dfrac{I_k}{\rho_k^3}}{\dfrac{\varphi_c}{\rho_c}+\dfrac{\varphi_k}{\rho_k}} \qquad (1)$$

where h - Planck's constant (6.6261·10^{-34} J·s);l

m_ϵ - electron mass (9.1094·10^{-31} kG);

c - speed of light in vacuum (2.9979·10^{8} m/s);

J_X - damping coefficient of the radial tune,

I_c and I_k - integrals $\int_0^{L_i} H\,ds$

$H = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$

α_x, γ_x - Twiss's parameters,

β_x, η_x - amplitude and dispersion functions of the storage ring;

β_x', η_x' - derivatives of β_x, η_x in the longitudinal coordinates, respectively;

ρ_c and ρ_k - radii, φ_c and φ_k are the beam bending angles for central and external magnets, respectively.

As is seen from formula (1), the lowest emittance can be attained only by minimizing I_c, because ρ_c is considerably smaller than ρ_k.

We have analysed the possibility of extending the special range of photon beams from the dipole magnets of the ISI-800 storage ring [2] by replacing the central magnet of the TBA cell with the superconducting one, whose field is 7 times higher than the fields in the outer magnets of the cell. The traditional and modified superperiods of the ISI-800 are schematically shown in fig.1.

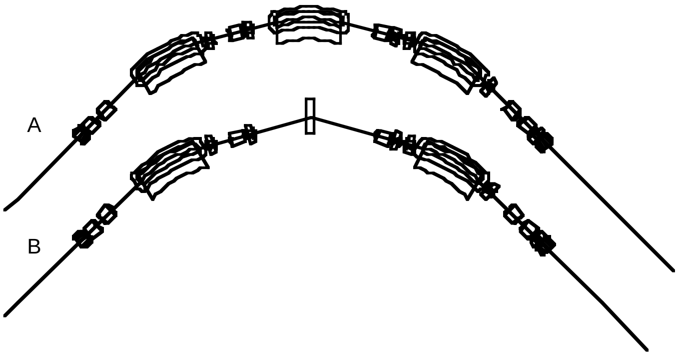

Fig.1. Schematic representation of the ISI-800 superperiod (A - traditional, B - modified).

Substituting the relationships $7\rho_c = \rho_k$ and $\varphi_c = \varphi_k$ into formula (1), we obtain

$$\varepsilon^*_{x\,TBA} = \frac{55}{32\sqrt{3}} \frac{h}{2\pi m_e c} \frac{\gamma^2}{J_x} \frac{343 I_c + 2 I_k}{9\rho^2\varphi} \qquad (2)$$

The procedure described in [1] can be used to derive the followingexpression for I_c:

$$I_c = \gamma_0 \eta_0^2 \frac{L}{2} - 2\gamma_0\eta_0\rho\left(\frac{L}{2} - \rho\sin\frac{L}{2\rho}\right) + \frac{1}{2}\beta_0\frac{L}{2}$$

$$-\frac{1}{4}\beta_0\rho\sin\frac{L}{\rho} + \frac{3}{4}\gamma_0\rho^2 L - 2\gamma_0\rho^3\sin\frac{L}{2\rho} + \frac{1}{4}\gamma_0\rho^3\sin\frac{L}{\rho}$$

(3)

Proceeding from the condition that in the symmetry plane (in the centre of magnet) $\alpha_0 = 0, \ \rightarrow \gamma_0 = \frac{1}{\beta_0}$, and finding the minima $\frac{\partial I_c}{\partial \eta_o} = 0, \ \frac{\partial I_c}{\partial \beta_o} = 0,$ we may obtain

$$\eta_0^* = \rho - \frac{2\rho^2}{L}\sin\frac{L}{2\rho};$$

$$\beta_0^* = \sqrt{\frac{3L\rho^2 - \rho^3\left(8\sin\frac{L}{2\rho} + \sin\frac{L}{\rho}\right) - 2L\eta_0^{*2}}{L - \rho\sin\frac{L}{\rho}}}$$

(4)

The substitution of the L and ρ values chosen for the ISI-800 into these expressions gives $\eta_0^* = 0.022$ m, $\beta_0^* = 0.1358$ m.

The contribution of the central magnet to the emittance value at a beam energy of 0.8 GeV is calculated to be $\varepsilon_x^* = 1\cdot 10^{-8}$ mrad.

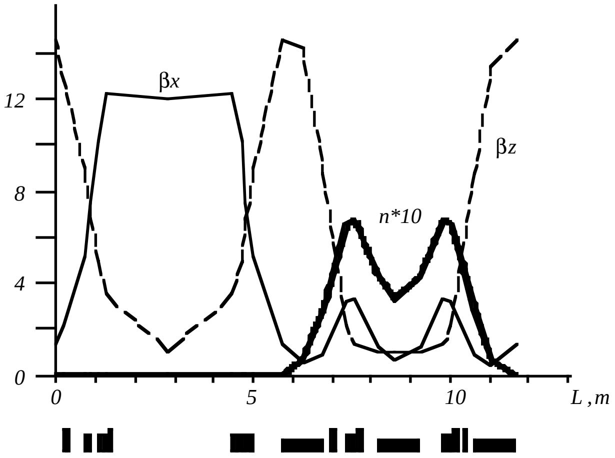

Fig.2. Structural functions of the traditional TBA cell.

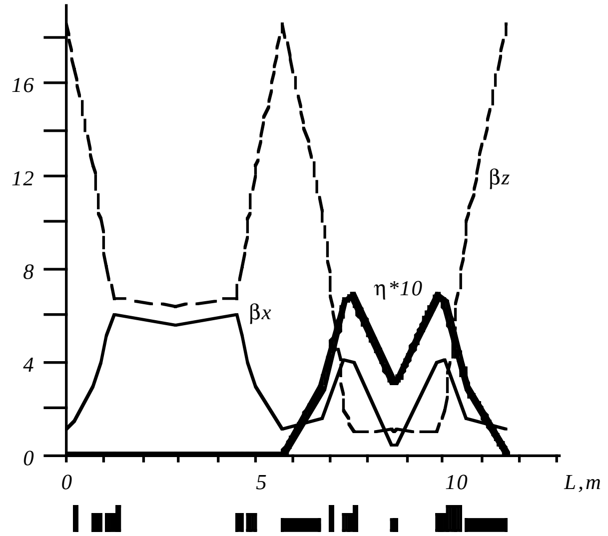

Fig.3. Structural functions of the modified TBA cell.

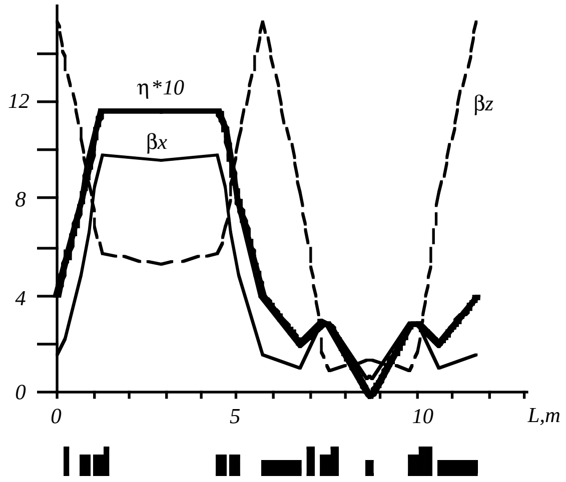

Fig.4. Structural functions of the modified TBA cell under low emittance conditions.

Figures 2, 3 and 4 show the structure functions computed with the DeCA code for the traditional TBA cell and the modified TBA cell of the ISI-800 storage ring [3]. It is seen that in the centre of the middle magnet the relations

$\eta_0 \approx \eta_0^*$, $\beta_0 \approx \beta_0^*$ can be provided only under operating conditions of nonzero dispersion in long straight sections (fig.4). The contribution of the middle superconducting magnet to the emittance value is close to the predicted value ($\varepsilon_x^* = 2 \cdot 10^{-8}$ mrad). For comparison, Table 1 lists the values of the parameters for different variants of the ISI-800 storage ring lattice.

Table 1 Lattice parameters of the ISI-800 storage ring

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.

Thus, from the comparison between the characteristics of the ISI-800 based on traditional "warm" magnets with special inserts (of wiggler type) and the combined lattice with the central 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.

Thus, from the comparison between the characteristics of the ISI-800 based on traditional "warm" magnets with special inserts (of wiggler type) and the combined lattice with the central superconducting magnet in the TBA cell it is evident that the latter has the following advantages:

(i) a greater number of channels for photon beams with a hard spectrum;

(ii) a wide range of beam emittance variation with the storage ring tune remaining the same (ε_x=$4 \cdot 10^{-8} \div 6 \cdot 10^{-7}$ mrad);

(iii) physically, the superconducting dipole magnet is considerably easier in manufacture than the wiggler is;

(iv) the influence of superconducting dipole magnets in the centre of the TBA cell on the beam dynamics and the actual aperture is insignificant because of the smallness of the structure functions at the place of magnet location.

The construction of the synchrotron radiation source ISI-800 with the combined TBA cell as a basis will ensure the conduction of photon beam studies in the ranges of vacuum ultraviolet and hard X-ray radiation.

REFERENCES

1. H.Wiedemann "Storage Ring Optimization" 1991' in Handbook on Synchrotron Radiation, vol. 3, ed. G.S.Brown, D.E.Moncton (North-Holland, Amsterdam) ch.1

2. V.Bar'yakhtar, E.Bulyak, et al. "A Source of Synchrotron Radiation for Research and Technology Applications" *Proc.PAC93 (Washington, 1993)*

3. P.G, A.Zelinsky, M.Strelkov "The Application Package DeCA for Calculating Cyclic Accelerators" *Proc.PAC93 (Washington,*

Parameter	**TBA**	**Modified TBA**	**Modified TBA with a low emittance**
Nominal energy, MeV	800	800	800
Stored current, mA	200	200	200
Circumference, m	46.729	46.815	46.815
Number of dipole magnets	12	8+4	8+4
Radius of magnet bend, m	2.005	2.005/0.267	2.005/0.267
Magnet length, m	1.05	1.05/0.14	1.05/0.14
Betatron numbers, ν_x/ν_z	4.26/3.20	4.26/3.20	4.26/3.20
Momentum compaction factor, α	0.025	0.023	0.021
Natural chromaticity, ξ_x/ξ_z	-7.27/-7.24	-6.2/-6.7	-6.2/-6.7
Damping times $\tau_x/\tau_z/\tau_s$,	8.7/13.8/9.8	7.2/7.9/4.1	8.4/9.9/5.4
Emittance, mrad	$2.7 \cdot 10^{-8}$	$6. \cdot 10^{-7}$	$4. \cdot 10^{-8}$
Beam size in the centre of the superconducting magnet σ_x/σ_z		0.54/0.25	0.15/0.07
Energy spread, %	0.058	0.122	0.125
Energy losses per turn, keV	18.3	57.4	57.4
Critical photon energy from the supercoducting magnet, keV		4.2	4.2