PROJECT OF 2 GeV SYNCHROTRON LIGHT SOURCE FOR THE REPUBLIC OF KAZAKHSTAN

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Abstract

Applications of synchrotron radiation (SR) are very popular for last time in many research fields. Thus a developing of compact source for generation of hard X-ray synchrotron radiation is very actual task. The goal of this work is a developing project of SR source for Republic of Kazakhstan. This storage ring mainly dedicated for performing the high sensitive X-ray fluorescence analysis of different natural samples to be used for ore exploration, ore processing and metallurgy . But implementations of other popular techniques applied for research and education with using synchrotron radiation (XAFS, XRD, etc) are also possible. This report includes a detailed description of main parameters and magnetic structure of designed storage ring as well as preliminary design of injector system.

INTRODUCTION

The growth of Kazakhstan industry demands the developing modern methods of element analyses for ore exploration and processing. In order with traditional for XRF "light" elements Z<30 (Ti, Cr, Mn, Co, Ni, Cu, Zn) there is necessity to have express and precision methods of determination Nb, Mo, Pd, Ag, Cd, In, Sn (41<Z<50) and Hf, Ta, W, Re, Pt, Au, Th, U (Z>70), that requires hard X-ray radiation with the photon energy up to100 KeV.

To provide this requirement the electron beam working energy is planed to be 2 GeV and hard X-ray flux is possible due to using superconducting bending magnet with maximal field value up to 8.5 Tesla. Thus critical photon energy for chosen energy and magnetic field values is 20 keV, that enough for fluorescence analysis of U by studying L and K-series [1].

Horizontal equilibrium emittance should correspond to the modern synchrotron light sources of 3rd generation, but with circumference of moderate size, providing moderate capital and operation cost. Moreover the number of SR channels for XRF analysis and other synchrotron radiation techniques should be as large as possible.

LATTICE CHOICE

Based on above demands and considerations we chose the emmitance as about 10 nmrad as desired target and tried to find the appropriate lattice.

Background

The well-known formula for theoretical minimum emittance is as follows:

$$\varepsilon_x = \frac{C_q\gamma^2}{J_x}\frac{\oint \frac{\mathscr{H}(s)}{\rho^3(s)}ds}{\oint \frac{ds}{\rho^2(s)}} = \frac{C_q\gamma^2}{J_x}\frac{I_5}{I_2} = \frac{C_q\gamma^2}{J_x}A \quad (1)$$

where A is part concerning integration, C_q=3.84·10 $^{-13}$ m·rads, γ is relativistic factor, ρ is bending radius, θ is bending angle, J_x is damping coefficient.

Integrating over all dipole magnets within the cell and assuming that dipole field is isomagnetic (i.e. magnets have constant radius) one can rewrite A from (1) as [2]:

$$A = \frac{\sum_i \frac{\int_{L_i} \mathscr{H}\, ds}{\rho_i^3}}{\sum_j \frac{L_j}{\rho_j^2}} = \frac{\sum_i \frac{\int_{L_i} \mathscr{H}\, ds}{\rho_i^3}}{\sum_j \frac{\theta_j}{\rho_j}} \quad (2)$$

If for dipole magnets the values of optical functions satisfy the conditions for theoretical minimum emittance, then [3]:

$$\frac{\langle \mathscr{H} \rangle_{\min}}{\rho} = K\theta^3 \quad (3)$$

where $K = \frac{1}{12\sqrt{15}}$ for central magnet and $K = \frac{1}{4\sqrt{15}}$ for side magnet (dispersion matching cells).

Then equation (2) can be written as:

$$A = \frac{\sum_i \frac{\langle \mathscr{H} \rangle L_i}{\rho_i^3}}{\sum_j \theta_j / \rho_j} = \frac{\sum_i \frac{K_i\theta_i^4}{\rho_i}}{\sum_j \theta_j / \rho_j} = \frac{\sum_i K_i\theta_i^4 \langle B_i \rangle}{\sum_j \theta_j \langle B_j \rangle} \quad (4)$$

where $\langle B_i \rangle$ is mean magnetic field value over magnet of *i*-th type.

Equation (4) allows performing the estimation of theoretical minimum emittance for different lattice types, consisting of different dipole bend magnets.

Taking into account the necessary of using superconducting magnet for hard X-ray generation the appropriate lattice type seems TBA cell with superconducting bend magnet (superbend) as central magnet and 2 conventional "warm" dipole magnets as side magnets.

For TBA case with different central and side magnets formula (4) can be rewritten as:

$$A = \frac{1}{12\sqrt{15}} \frac{\theta_c^4 \langle B_c \rangle + 2 \cdot 3 \cdot \theta_s^4 \langle B_s \rangle}{\theta_c \langle B_c \rangle + 2 \cdot \theta_s \langle B_s \rangle} \quad (5)$$

where indexes c and s denote central and side magnets correspondently.

In 2004 BINP fabricated a 9 Tesla Superbend for BESSY-II storage ring (Berlin, Germany). This magnet can be a prototype for current project. Some design details will be discussed later, but a typical field integral value of this magnet (about 1.6 T m) can be used for choice of bending angle for 2 GeV electron beam. The theoretical minimum emittance in that case is equal to 8.2 nmrad for 20^0 bending angle of each magnet according Eq. 5. In next sections the more detail description of accelerator storage ring lattice based on TBA cell is done.

TBA lattice with non-zero dispersion

The major parameters of TBA lattice with 6 cells are given in Table 1.

Table 1: Lattice parameters

Energy (GeV)	2
Circumference (m)	135
Beam current (mA)	500
Horizontal emittance (nmrad)	6
Number of cells	8
Superbend/"Warm" dipole field (T)	8.5/1.6
Superbend/"Warm" dipole bend angle (deg.)	10/17.5
Number of straights	8
Full length of straights (m)	42
Betatron tune (horiz; vert)	4.69; 2.62
Natural chromaticity (horiz; vert)	-23.9; -4.2

The layout of the lattice cell and plot of the beta and dispersion functions are shown in figure 1. Both the horizontal beta function and dispersion are symmetric within the superbend and conventional dipole magnets, reaching the minimum at their centers. The dispersion at straight section is non zero and has value of about 0.4 m. The emittance value generated on superbend magnet is about 20% of its value on normal conducting dipole. The corresponding electron beam size at magnet center is 25 μm, that provides good radiation source properties.

Note that since the bending angle is large enough as 20^0 it is possible to organise 4 synchrotron radiation channels from each superbend without problems related to space issue. So the total amount of proposed 24 keV critical photon energy SR channels for this storage ring structure is assumed to be 24.

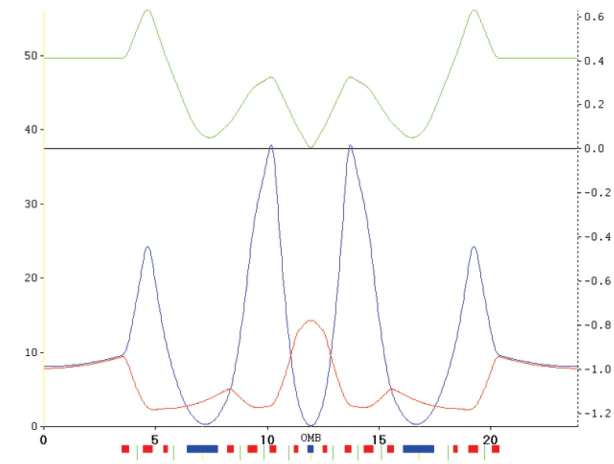

Figure 1: Lattice functions and cell layout (blue is horizontal beta, red is vertical beta, top plot is dispersion).

TBA lattice with zero dispersion

Lattice functions for zero dispersion at straights are presented in figure 2. The lattice layout is left the same as previous one, but values of gradient of quadrupoles are correspondingly changed. The emittance grows in this case to 29 nmrad. Although emittance value becomes essentially larger it is possible at zero dispersion mode to install damping wigglers into 7 m long straights to reduce emittance value. The ways of emittance reducing for zero dispersion regime is subject for further studying.

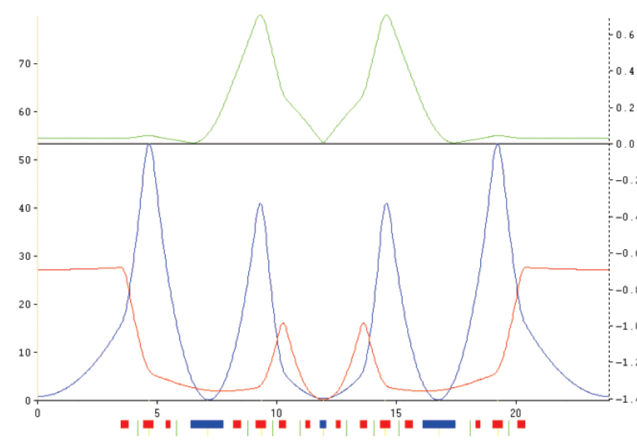

Figure 2: Lattice functions for zero dispersion mode (blue is horizontal beta, red is vertical beta, top plot is dispersion).

9 T SUPERBEND MAGNET

The design of central dipole magnet for TBA cell is based on 9 Tesla superconducting bending magnet constructed for BESSY-2 storage ring [4]. The general parameters of 9 T superbend is summarised in Table 2.

Table 2: Parameters of superbend magnet.

Vertical/horizontal aperture (mm)	30/75
Pole gap (mm)	46
Operating magnetic field (T) Maximum magnetic field (T)	3.3-8.5 9.6
Coil material	Nb_3Sn, NbTi
Current in coil for 8.5 T (A)	264
Ramping time 0-7 T/0-9 T (min)	<5/<15
Eff. Magnetic length along beam (m)	0.1777
Bending angle (deg.)	11.25 (for 1.9 GeV)
Stored energy for 8.5 T (kJ)	180

Superbend magnet consists of 2 superconducting coils assembled above and below of vacuum chamber. The coil consists of five sections winding around magnetic steel core. The first and second sections are wound from Nb_3Sn wire and third section is from NbTi wire. The forth NbTi section is used for correction. The magnetic steel pole has a shimming notch to obtain necessary transverse field homogeneity. The magnet implies the magnetic steel yoke, so the fridge magnetic fields are very low. Figure 3 presents the drawing and picture of the superbend magnet.

Figure 3: General view and picture of 9 T superbend magnet.

OTHER SYSTEMS

Here we briefly discuss the key components of accelerator complex, which are assumed to be produced from state-of-art systems, i.e. previously developed and manufactured at BINP. The electron linac is planed as having energy of 100 MeV. The booster synchrotron should satisfy the following specification:

- full energy injection
- repetition rate 1-3 Hz.

The magnetic elements and support structures of main storage ring are planed to be produced the same as ones designed and produced for Swiss Light Source by BINP. RF system can be standard BINP's 180 MHz system with high order mode suppression.

SYNCHROTRON RADIATION OUTPUT

Figure 4 shows the photon spectrum from 9 T superbend magnet for 2 GeV electron energy and 500 mA current. 24 synchrotron radiation channels with such spectrum will be used for XRF analysis performing for purposes of ore exploration and processing as well as for other applications utilising hard X-ray radiation.

The developed storage ring lattice allows to accommodate up to 6 straights, length of each can be up to 7 m. These straights may be used for installation of different type undulators and wigglers.

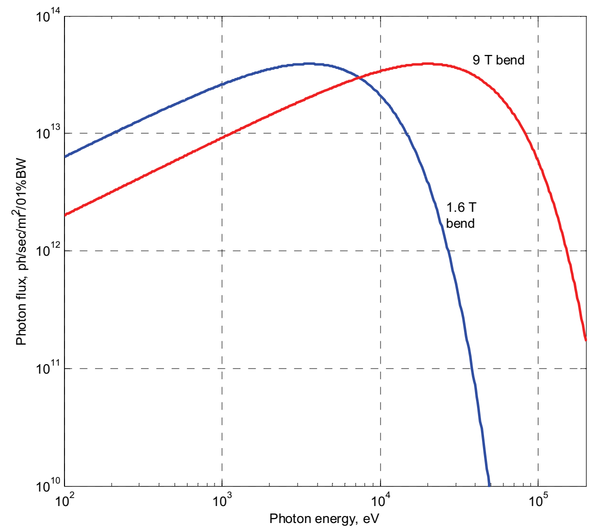

Figure 4: Synchrotron radiation spectrum from 9 T superbend magnet, E=2 GeV, I=500 mA.

CONCLUSION

The designed storage ring satisfies requirements imposed for modern 3rd generation light sources. Otherwise one seems to be economical and compact due to employing superconducting 9 Tesla bend magnets and standard key accelerator systems, developed at Budker INP. The main application of this light source is fluorescence analysis for ore and mettalurgy industry with hard X-rays from superbend. But the other widely used techniques like EXAFS, X-ray diffraction, microscopy, tomography, etc. also can be provided with recent light source design aiming the variety of research, industrial and educational purposes.

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