THE DEDICATED SYNCHROTRON RADIATION SOURCE «SIBERIA-2»

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1. Introduction

At present in the Institute of Nuclear Physics (Novosibirsk, USSR) the dedicated synchrotron radiation (SR) source electron storage ring Siberia-2 [1] is created for the Institute of Atomic energy (Kurchatov Institute, Moscow, USSR).

The facility is intended for the experiments with SR in the atomic and molecular spectroscopy, in the field of solid state physics, crystallography, biology researches, EXAFS-spectroscopy of the amorphous materials, trace element analysis, Mössbauer experiments, high time resolution experiments, Compton and nuclear spectroscopy.

2. General Description

The facility includes (Fig. 1) a small storage ring Siberia-1 (450 MeV) for works in soft X-ray and VUV ranges [2] and a main storage ring Siberia-2 (2.5 GeV) for researches in hard

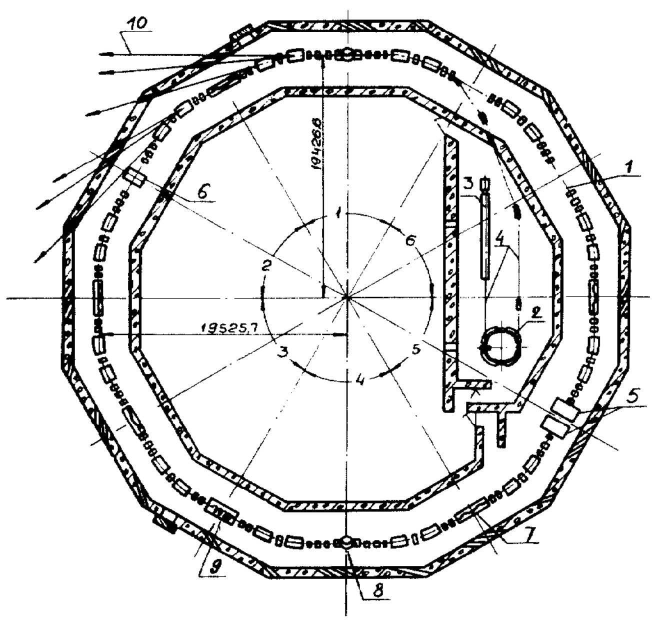

Fig. 1. Schematic of SR source «Siberia-2» showing the injection system (100 MeV linac (*3*) a 450 MeV booster storage ring Siberia-1, (*2*)) transport lines, storage ring lattice (*1*) and SR beam lines (*10*).

X-ray range. The small ring is also used as an injector in main ring. An injection system consists of a linac (80—100 MeV) and two transports lines for electron beams.

Siberia-2 is optimized to achieve high flux and brightness of synchrotron radiation. The lattice provides:

- installation of high field superconducting wigglers to produce hard X-radiation;
- installation of undulators to emit bright SR in soft X-ray and VUV regions;
- optimization of the parameters of radiation from insertion devices without disturbing operation of storage ring.

Synchrotron radiation is taken out of bending magnets and insertion devices of Siberia-1 and Siberia-2. Of the 12 straight sections each about 3 meters long of main ring three are occupied by septum magnet and RF-cavities. Other 9 are available for insertion devices.

Minimization of the horizontal electron beam emittance is the most important condition for increasing spectral brightness. The achievement of low emittance and the optimal betatron and dispersion functions at the source points determine the lattice quite definitly.

3. Main Ring

The magnetic system of Siberia-2 is designed with separate functions. The lattice of the Siberia-2 consists of 6 mirror-symmetrical superperiods each containing achromat bend and two 3 m long straight sections. As it has been shown in [3] for storage ring with achromats the minimum horizontal emittance determined by quantum fluctuations can be estimated as

$$\varepsilon_{x\,\min} = kE^2\varphi_m^3\,,$$

where E—energy of electrons, $\varphi_m = \pi/N$—bending angle, N—number of superperiods, k—constant depending on the lattice.

For the chosen magnetic structure of the Siberia-2 we have

$$\varepsilon_{x\,\min}\,(\mathrm{cm\cdot rad}) \simeq 10^{-5}\cdot E^2(\mathrm{GeV})\cdot\varphi_m^3\,(\mathrm{rad}) \simeq 7.8\cdot 10^{-6}\mathrm{cm\cdot rad}\,.$$

From the functional point of view the half of superperiod consists of two parts (Fig. 2). The first part comprising quadrupoles F_1, D_1 F_2 and bending magnets is responsible for achromat bend

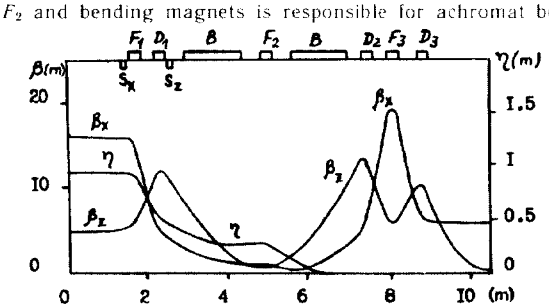

Fig. 2. Lattice functions through one unit cell of a half-superperiod.

and high β_x, β_z functions in undulator straight section. The second part comprising quadrupoles D_2, F_3, D_3 and dispersion-free straight section allows to change the betatron tunes not disturbing the achromat bend and to compensate locally for the betatron tune shifts due to the wigglers preventing rise to noticeable beating in the structural functions on the ring.

Optimization of behaviour of horizontal betatron and dispersion functions in bending magnets permits to obtain the minimum emittance. In all magnets $\beta_x \leqslant 3.5$ meters and at the source points it is equal 2.5 and 0.6 meters.

In undulator straight section the betatron functions are large enough to obtain low divergent electron beam: $\beta_x = 17$ m, $\beta_z = 6$ m. Dispersion function is small here: $\eta_x = 80$ cm.

High-field superconducting wigglers are located in the dispersion-free straight sections and can be used for reducing the emittance.

The vertical β_z-function in the centre of the wiggler section is small ($\sim$0.5 m). This guarantees a small shift in the vertical betatron tune when installing strong-field wigglers. The horizontal β_x-function is equal to 6 m.

Designed lattice has relatively small natural chromaticity. To compensate it to the chromaticity there are two families of sextupole lenses (in vertical and horizontal directions) in undulator sections. The necessity of using the large number of the sextupoles leads to the limit of dynamic aperture because of nonlinear dependence of the betatron tunes on the oscillation amplitudes and the excitation quite power resonances of the third order. The dynamic aperture due to these sextupoles is shown in Fig. 3.

The chamber aperture, free for the beam, has been chosen to be equal to ± 30 mm in horizontal and ± 16 mm in vertical planes.

Siberia-2 has harmonic number $q=75$ and momentum compaction factor $\alpha=0.0076$. This guarantees producing very short electron bunches ($2.35\sigma_s=4.4$ cm) necessary for high time resolution spectroscopy experiments.

At a large current of stored beam the main effect limiting beam lifetime is the Touschek scattering. The bunch lengthening is likely to be the most effective method of increasing the lifetime. This

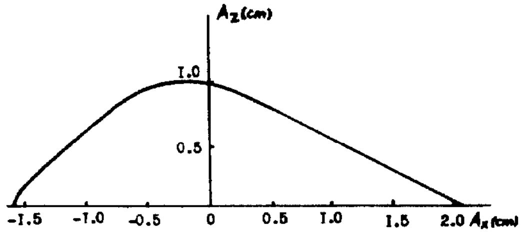

Fig. 3. Dynamic aperture of the magnetic structure of Siberia-2.

is achieved by powering an additional RF voltage of a 225th harmonic of revolution frequency. For this purpose, a 541 MHz cavity is put into one of the Siberia-2 straight section.

Table 1 summarized the main parameters of Siberia-2.

Table 1

Energy, E, GeV	2.5
Orbit circumference, P, m	124.13
Number of superperiods, N	6
Number of dipoles, N_d	24
Magnetic field in bending magnets, $B_{1,2}$, T	0.425; 17
Bending radii, $R_{1,2}$, cm	1962.16; 490.54
Number of quadrupoles, N_q	72
Number of 3 m long sections ($\eta=0$), N_w	6
Number of 3.18-m long sections ($\eta\neq0$), N_u	6
Number of sextupoles, N_s	24
Betatron tunes, ν_x, ν_z	7.731; 7.745
Momentum compaction factor, α	$7.6\cdot10^{-3}$
Chromaticity, ξ_x, ξ_z	-25.3; -22.2
Horizontal emittance, ε_x, cm·rad	$7.65\cdot10^{-6}$
Damping times, τ_z, τ_x, τ_s, ms	3.04; 3.14; 1.5
R.m.s. energy spread in the beam, σ_E/E	$0.955\cdot10^{-3}$
Energy loss per turn (without the wigglers and undulators), ΔW, keV	681.1
Revolution frequency, f_0, MHz	2.4152
RF harmonic number, q	75
RF voltage, V_{RF}, kV	1800
RF frequency, f_{RF}, MHz	181.14
Current, I, mA	
a) single-bunch mode of operation,	100
b) multi-bunch mode of operation	300
Energy aperture, $(\Delta E/E)_{max}$	$\pm2\cdot10^{-2}$
Lifetime (single-bunch mode of operation: current 100 mA and the coupling factor $\varkappa\sim0.2$) due to the Touschek effect, τ_T, h	~10
Bunch length ($V_{RF}=1800$ kV, $2.35\sigma_s$, cm	4.4

4. Injection to Siberia-2

The electrons are injected to Siberia-2 at 450 MeV energy in a horizontal plane. The injected beam has the energy spread $\sigma_E/E=0.39\cdot10^{-3}$ and its horizontal emittance is $\varepsilon_x=8.6\times\times10^{-5}$ cm·rad, both being determined by quantum fluctuations of SR. The storage ring Siberia-2 is capable of operating in two regimes: single-bunch ($I=100$ mA) and multi-bunch ($I=300$ mA). The maximum possible bunch repetition rate in the storage ring is determined by the RF frequency of a cavity, $f_{RF}=181$ MHz, and the shortest repetition period is about 5.5 ns. Irrespective of the type of injection — to one separatrix or to many neighbouring ones — the beam is stored using the pre-kick. When designing the scheme of injection, the fact has been born in mind that, with the achromatic bend incorporated in the superperiod, the betatron phase advance is exactly $\pi/2$, from the beginning of this superperiod to the centre of the lens F_2.

Small residual oscillations of the beam being injected decay with the damping time, $\tau_x=0.54$ s. At the injection energy, the equilibrium sizes of the electron beam are determined by the Touschek effect.

The injection procedure is repeated with a frequency given by the booster, the storage ring Siberia-1. The expected rate of current storage for a circulating of about 100 mA is roughly equal to 10—20 min.

5. Magnet System

5.1 Bending magnet.

There are 24 dipole 15° bending magnets of an O-configuration (as shown in Fig. 4) which are made of ARMCO magnetic steel. All magnets are electrically connected in series. The pole of each magnet is divided into two parts: the long one with main field and the more shorter one with the field that is equal 1/4 of main field. A shorter part of magnetic pole adjoins to the long wiggler's or undulator's straight section. So there are 12 left and 12 right dipole magnets. This construction separates spatially the radiation of magnets from that of wiggler, as well as reduces the overheating of the superconducting system in straight section due to radiation of the magnet edge. The bending magnet cross section and a plan view are shown in Fig. 4*a*, 4*b*.

As magnetic measurements has shown the value of relative dipole magnetic field strength is $|\Delta B/B|\leqslant10^{-3}$ in the required radial aperture $2a_x=60$ mm and the sextupole component is less than 3 Gs/cm^2. To avoid the dependence of effective length of bending magnet on the magnetic field amplitude there are 45° cutoffs having 41 mm for external edge of main pole and 38 mm for its enternal edge. With such cutoffs the effective length is equal to geometrical one.

To compensate for a disbalance between the fields in the long and short parts of the pole due to their nonsimultaneous magnetic saturation there are correcting coils in every magnet on the short part of the pole. The geometrical aperture of dipole magnet is large enough in horizontal direction to extract synchrotron radia-

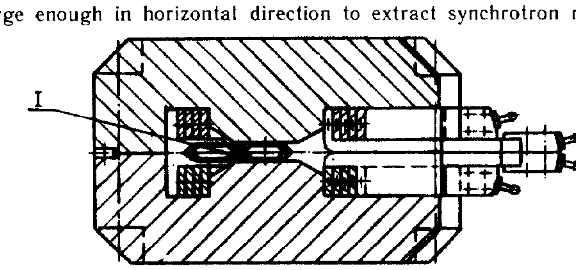

Fig. 4a. Storage ring bending magnet cross section.

tion both from magnet itself and from insertion device located in straight section.

5.2. Lenses.

In magnetic structure of Siberia-2 there are 72 quadrupole lenses series-connected in 6 families with 12 lenses in each family. The quadrupoles of the long straight sections have a closed magnetic yokes and are combined in «doublet» and «triplet» magnetic blocks for higher accuracy in their manufacturing and the convenience in the survey and alignment. Opposite to the single lenses located in between the bending magnets have opened magnetic yokes having two C-shape parts (upper and lower). It is necessary for extraction of radiation from superconducting wigglers. All quadrupoles have the dipole and gradient correction windings.

According to magnetic measurements the nonlinear dependence of the field gradient on the excitation current arising from the magnetic saturation is less than 8% at a current of 0.8 kA, relative field gradient is $|\Delta G/G|\leqslant10^{-3}$ within a circle aperture of 2 cm in radius at the maximum gradient value.

The quadrupole is designed so that SR beam with the horizontal size being equal to ±5 cm can pass through its vacuum chamber.

Besides the main magnet elements there are four families each incorporating 6 sextupoles (first two families compensate for a natural chromaticity and second two families, located in dispersion-free area, increase the dynamic aperture), two 6-octupole families for controlling the cubic nonlinearity and skew-quadrupole coils placed at octupole yokes for controlling vertical beam size.

Table 2 summarizes the main works parameters of the magnetic elements at the energy of 2.5 GeV.

Table 2

Parameter	Bending magnet	Quadrupole lenses			Sextupole lenses
Number	24	48	12	12	24
Max. magnetic strength	1.7 T; 0.425 T	35 T/m	35 T/m	35 T/m	840 T/m^2
Effective length, cm	124.3; 16.7	30	40	31.5	11
Aperture gap or diameter, mm	42	56	56	56	59
Bending radius, m	4.906; 19.626	—	—	—	—
Max. current, A	7200	680	760	680	25
Power, kW	22.8	4.36	6.51	4.36	0.545
Cooling	water		water		air

6. Vacuum System

Aluminium vacuum chamber in bending magnets and lenses are built by using extrusion techniques. A vacuum of $3\cdot10^{-9}$ Torr (in nitrogen equivalence, $z\simeq7$) is required to obtain beam lifetime

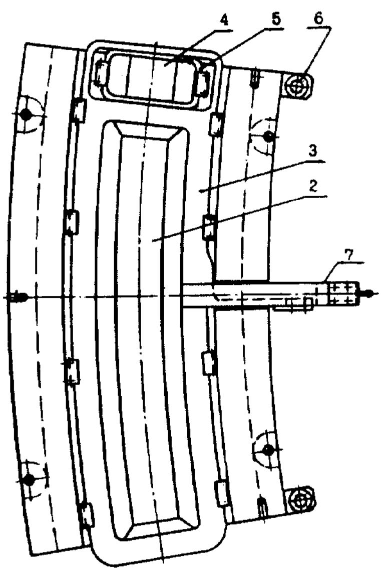

Fig. 4b. Storage ring bending magnet plan view.

~10 hours with the electron current ~0.3 A. The photon-induced desorption defines the pumping rate 72000 liters/s. Radiated power at the energy of electrons 2.5 GeV and current 0.3 A is 34 W in 1 mrad of horizontal angle.

There are 62 complicated pumps (pumping ~1000 liters/s) that consists of magnetic-discharged pump and titanium sublimator pump and 12 separate titanium sublimator pumps with pumping 200 liters/s.

To obtain required pressure in RF-cavities two special titanium sublimator pumps (pumping 3000 liters/s each) and two magnetic-discharged pumps (700 liters/s each) are in use.

Heat cleaning of the surface of vacuum chamber is carried out at temperature 160°C for aluminium part and 300°C for steel parts during 24 hours. After that only synchrotron radiation cleaning takes place. We hope that total integral of electron beam current ~50 A·hours maintain vacuum lifetime ~10 hours. The different parts of the vacuum chambers are separated from each other by 24 automatic shutters. The separation of the SR vacuum lines and the storage ring vacuum system is realized by means of analogous shutters.

7. RF-System

RF-system of Siberia-2 provides the voltage 1.8 MV on two accelarating cavities with the frequency 181 MHz. Power for compensating radiation losses is ~300 kW at 2.5 GeV with maximum beam current of 300 mA. The loss Power in the cavity walls is 90 kW. So, the total output power of RF-generator is 400 kW. In order to get high reliability RF-system has two channels with independent cooling, supply, safe and control of each one. The total power consumed by RF installations is 1.2 MW.

Accelerating cavities are made of copper, cylindrical type. They are excited on E_{010} oscillation type. The tuning of cavities is carried out by the bend of plain walls with the help of electric motors.

8. Main Parameters of Siberia-2 Source

Synchrotron radiation from Siberia-2 is taken out of bending magnets (beams 5°20′ and 17° Fig. 5), «wiggler» straight section (Sec. 1) and «undulator» straight section (Sec. 2) identically in

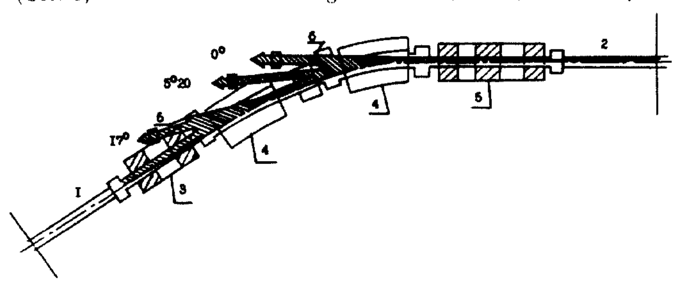

Fig. 5. Plan view of one sector of the storage ring showing radiation transmitted to the beam lines.

each superperiods (see Fig. 5). The values of β-, η-functions, meansquare dimensions and angles of electron beam in radiation points are shown in Table 3.

Table 3

$E=2.5$ GeV, $I=300$ mA, $\varepsilon_x=8\cdot10^{-6}$ cm·rad;
$\nu_z=7.745$, $\varkappa=0.01$, $\varepsilon_z=8\cdot10^{-8}$ cm·rad;
$\nu_x=7.731$, $\sigma_E/E=0.96\cdot10^{-3}$;

Radiation point	β_x m	β_z m	η_x cm	η' mpad	$\sigma_{x\beta}$ mm	σ_{xs} mm	$\sigma_{x\ tot}$ mm	$\sigma_{x'}$ mrad	$\sigma_{z'}$ mrad	$\sigma_{z\ tot}$ mm
Sec. 1	17.3	6	75	0	1.18	0.72	1.38	$\sigma_{z\ tot}$	0.017	0.070
5°20′	2.5	8.25	30	−40	0.45	0.29	0.53	0.18	0.010	0.08
17°	0.58	1.75	14	−230	0.22	0.13	0.26	0.44	0.021	0.037
Sec. 2	6.5	0.25	0	0	0.72	0	0.72	0.11	0.056	0.014

Parameters SR beams of Siberia-2 are shown in Table 4.

Table 4

Max. electron energy, GeV	2.5
Max. stored current, mA	
single bunch mode	100
multibunch mode	300
SR spectral range, Å	2000—0.1
Characteristic wavelength of SR λ_c, Å	
from bending magnet	1.75, 7
from superconducting 3-pole wigglers	0.25—0.4
from undulators	20
Pulse duration of SR, ns	0.14
Time interval between SR-pulses, ns	5.5—414
Number of beamlines	
from bending magnets with horizontal angles ±5 mrad	24
from two superconducting 3-hole wigglers with horizontal angles +1°40′ ÷ −1°20′	10
from undulators	up to 5

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