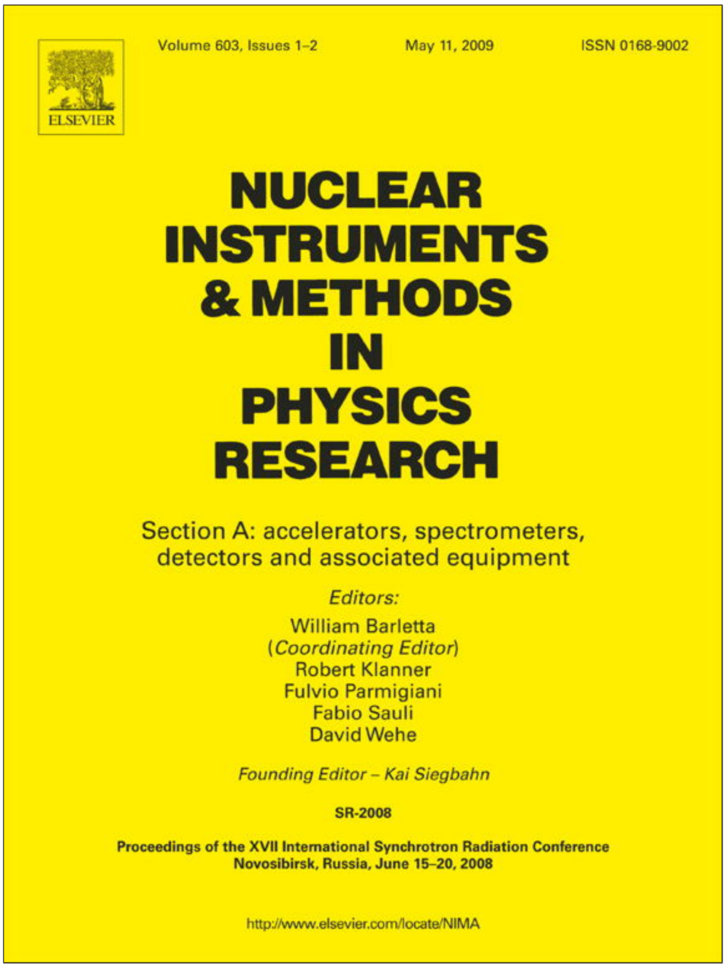

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Status of the ‘‘Zelenograd’’ storage ring

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ABSTRACT

In 2000, after a long break, creation of the technological storage ring complex (TSC) was renewed in ZELENOGRAD. The injection complex has now been commissioned. The equipment of the main storage ring that has been made earlier is now under inspection. The status of, and short-range plans concerning the Zelenograd storage ring are described in the report.

1. Introduction

Synchrotron Radiation (SR) has given an opportunity to realize some new technologies such as X-ray lithography for manufacturing of submicron structure devices and LIGA-technologies for production of micro-mechanical tools. Currently, the main purpose of the project is creation of universal nanotechnology and metrology complex at Lukin Research Institute of Physical Problem (RIPP), Zelenograd in accordance with the Federal Nanotechnology Program.

Technological storage ring complex (TSC) is to meet challenges in the following fields:

- nanotechnologies and nanomaterials;
- technologies for microsystem engineering and mechanotronics with elements of the nanometer range;
- technologies of the up-to-date electronic components;
- technologies of medicine, bioengineering, etc.

The TSC complex has been developed and manufactured by Budker BINP SB RAS. The complex consists of a Linear Accelerator (LA) of 80 MeV energy and two Storage Rings: 450 MeV Booster and 2.2 GeV Main Storage Ring (MSR). The complex is intended for generation of bright SR beams in the infra-red, ultra-violet and X-ray areas of spectrum in the wavelength range of 0.1–2000 Å.

When the complex of specialized SR sources was under development, an optimization of the magnetic structure parameters was carried out in order to obtain minimum electron beam emittance and to provide maximum radiation brightness from bending magnets as well as to get the possibility to install insertion devices such as undulators, and strong field wigglers. The TSC was assumed to have more 30 beam line: 20 beam line from bending magnets; 10 beam line with use hard SR from superconducting wigglers; seven beam line with use soft and VUV SR from ‘‘warm’’ insertion devices.

2. Injection system of the MSR

The 80 MeV LA is an electron source for the Booster [1]. It was commissioned at Lukin RIPP (Zelenograd, Moscow) in 2002. Principle parameters of electron beam at the LA output that have now been reached are shown in Table 1 [1]. In 2007, a thermostabilization for the accelerating structure was assembled and put into operation. It was trained up to 80 MeV.

TL-1 is intended for transfer of electron beam from the LA to the Booster and for matching beam emittance with Booster

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acceptance at the LA output. TL-1 consists of a straight section with a quadrupole triplet and an area with two 12° bending magnets meant for parallel transfer of electron beam.

The Booster has the following parameters: the single-bunch energy 450 MeV, the electron current about 150 mA and longitudinal size σ_s=30 cm. Fig. 1 shows the BSR pre-inflector and inflector sections and the area of the injection channel. Section 1 is placed under the injection septum, RF cavity and beam current sensor. Inside the vacuum chamber of straight Sections 1 and 4, comprising quadrupole lenses and a vertical orbit corrector, there are plates of the pre-inflector and inflector. Sextupoles compensate chromatism in straight Sections 2 and 3. Section 4 has an octupole lens to compensate cubic nonlinearity of magnetic field. The extraction septum is placed in straight Section 3.

Injection into the Booster from the LA is carried out in a single turn in a vertical plane at an angle of 12° to the median plane. Multiple storage of particles is performed with pre-kick. The vertical acceptance is 5.6×10^{-3} cm rad.

From the Booster, the electrons are also extracted up in a vertical plane at an angle of 20° to the median plane. Before extraction, the orbit is corrected in the vertical direction and the beam is moved to the septum magnet. A 20 ns duration electromagnetic pulse from the plates of the deflector (which is the inflector in the accumulation mode) raises the beam path up to the septum magnet aperture. In the septum magnet, the extracted electron path is moved into transfer line TL-2. The Booster extraction cycle period should be about 0.5 min at a circulating beam current about 100–150 mA.

All elements of the Booster vacuum system are fabricated from stainless steel without any rubber or viton seals. The RF cavity insertion is ceramic. Either welded connections or metal seals are applied everywhere, which allows heating the vacuum chamber up to 250 °C.

Table 1
Linear Accelerator parameters.

Beam energy	80 MeV
Energy spread	1%
Pulse beam current	~80 mA
Pulse duration	15 ns
Transversal emittance	0.1 mrad cm
Repetition rate	1–2 Hz

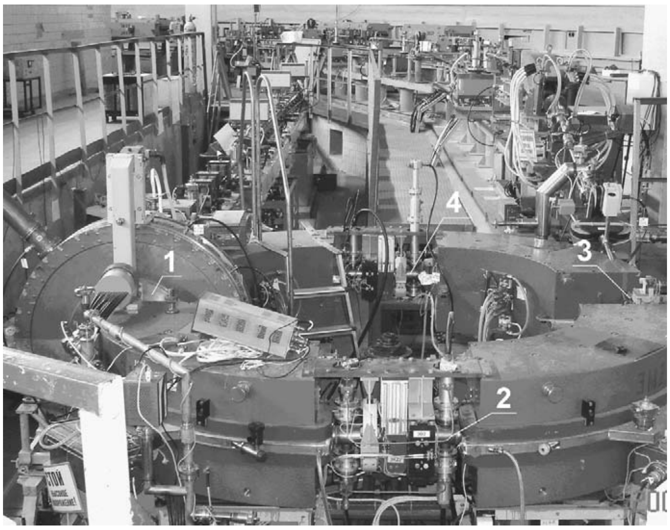

Fig. 1. Booster.

The RF system of the Booster provides the required amplitude of 15 kV of RF voltage in the cavity. For injection into the Booster into one RF separatrix, it is essential that the injected beam should be in a single bunch. That is why the first harmonic of the frequency 34.59 MHz is used.

TL-2 is intended for transfer of electrons from Booster into MSR. It includes: two 20° bending magnets providing vertical parallel transfer of beam, three horizontal 20° bending magnets for horizontal 60° horizontal bend of beam and six quadruples to match the beam transfersal parameters.

TL-2 has been assembled up to injection straight section of MSR. The vacuum chamber was pumped and heated up in order to start it up by the beginning of 2008.

3. Main Storage Ring (MSR)

When creating specialized storage rings intended to be SR sources, it is most important to reach bright spectral photon fluxes. The SR source magnetic structure should provide a possibility to install undulators and superconductive wigglers in straight sections for storing an electron beam of small emittance. In general, the necessity to reach high radiation brightness from the bending magnets, high-field multi-pole wiggler and undulator has been revised. Thereupon, the range of optimal behavior of the betatron and dispersion functions on the azimuths of these SR sources has been found. The optimal amplitude functions of the storage have a significantly different behavior on the azimuths of the bending magnets, wigglers and undulators. Table 2 shows principal parameters of the MSR to be a specialized SR source [2].

The calculated magnetic structure of the MSR consists of six mirror-symmetric super-periods. Each super-period has two 3 m straight sections for undulators, wigglers, injection and RF cavity. At 2.2 GeV energy, the horizontal emittance of electron beam is caused by quantum fluctuations of radiation. The basic stability range of betatron movement is within v_x=0.73, v_z=0.74.

The magnetic structure, amplitude functions $\beta_x(s)$, $\beta_y(s)$ and dispersion of one of the MSR super-periods are shown in Fig. 2. At the centers of the super-periods, inside the achromatic bends, there are sections where undulators and an injection septum magnet can be installed.

The MSR super-period structure consists of 12 quadrupole lenses and four bending magnets. Part of the structure that includes the undulator section, quadrupole lenses F1 and D1 and bending magnets B provides the possibility of achromatic bending and β_x, β_y, which are optimal for installation of undulator and sextupole lenses to compensate chromatism.

Table 2
Zelenograd main storage ring parameters.

Energy	2 GeV
Perimeter	115.73 m
Super period quantity	6
Bending magnets magnetic field	0.37; 1.5 T
Quantity of 3 m long sections	12
Betatron numbers	7.73; 7.74
Ratio of orbit spatial compression	9.9×10^{-3}
x, y Chromatism	−19; −20
Horizontal emittance	35 nm rad
Vertical emittance	0.35 nm rad
x, y, s-Damping time	4.15; 4.3; 2.0 ms
Turn frequency	2.5905 MHz
RF multiplicity	70
RF voltage	1200 kV
Current	
(a) Single-bunch mode	100 mA
(b) Multi-bunch mode	300 mA

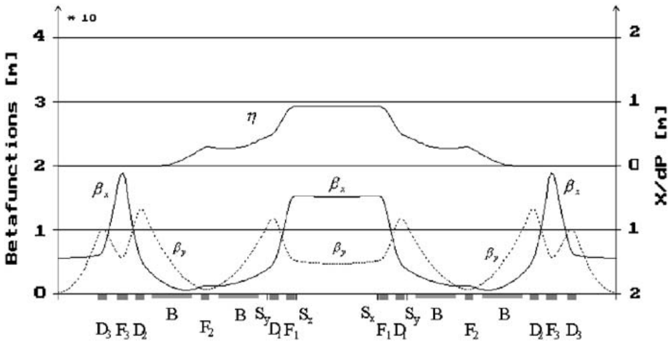

Fig. 2. Magnetic structure and amplitude function of MSR super-period.

Another part, including lenses D2, F3, D3 and wiggler section, provides frequency variations of betatron oscillations. It also provides generation of optimal β_x and β_y in the wiggler straight section. The 30° bending magnet is divided into two similar (mirror-symmetric) 15° magnets. The location of quadrupole F2 between the 15° bending magnets in the focus of the achromatic bend system provides the possibility of easy position control of minimum horizontal beta-function (from the right and left of lens F2) at reaching the necessary emittance. There is an opportunity to get an injection scheme with two inlet kickers placed on lense F2 azimuths inside one achromatic bend with a betatron phase incursion of $\pi/2$, between them. As a result of the bending magnet shortening, the construction of the vacuum chamber also gets easier as well as SR extraction.

Values of the bending magnet functions β_x and η are close to optimal. In each bending magnet the value β_x is 3.5 m or less. At points of radiation extraction, it equals 2.5 and 0.6 m, which provides radiation extraction from magnet with brightness close to the maximum one.

In the 3 m straight section, which is intended for placement of a super conductive wiggler with high magnetic field, the dispersion and its derivative are equal to zero (η_w=$\eta_{w'}$=0). That is why installation of wigglers gives us an additional possibility of emittance reduction. The horizontal beta-function at the center of the wiggler section, β_x=6 m, is sufficiently large. Its value is a compromise between an acceptable distinction of dispersion from zero in the wiggler section and, on the other hand, a necessary condition for high brightness at zero angle. The vertical β_y function is small (~0.5 m). That guarantees a small shift of the vertical betatron frequency at installation of high-field wigglers. In accordance with calculations, the betatron tune shift introduced by a super conductive wiggler with super high field is $\Delta\nu_y \sim 5\times10^{-3}$. It is easily enough compensated by these local areas, without introducing noticeable pulsations of structural functions in the ring.

4. Current status

All dipoles, quadrupoles, sextupoles, octupoles, multi-pole wigglers and undulators after long storing, are revised in BINP. The revision includes cleaning, electrical tests, mechanical and magnetic measurements and, if necessary, mechanical modification. Dipoles, sextupoles and octupoles have been delivered to Zelenograd in 2007, all quadrupoles will be delivered to Zelenograd in the end of 2008.

Besides, because of new Complex Control Systems, the modification of present and production of new power supply sources is carried out. The power supply for magnets of injection system have been delivered to Zelenograd and commissioned in 2007. Power supply systems with currents: 7.2 kA, 1.0 kA, 20 A, 5.0 A for different magnets of MSR are modified or produced and to be commissioned at TSC in 2008–2009.

All power supply for LA and Booster pulse elements were commissioned and are operating at the TSC. The generators for MSR are being assembled and commissioned.

RF system now under manufacturing in BINP and after all acceptance tests will be delivered on TSC in 2009.

All electronic units of Control system have been produced in BINP. They are ready to be delivered. Software for Control system is developed by Kurchatov Synchrotron Radiation and Nanotechnology Center.

Vacuum system of MSR are revised and tested. Dipole vacuum chambers are practically newly produced. We respect the assembling of vacuum system of MSR at the 2009.

Thus the MSR will be commissioning in 2009.

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