STATUS OF "ZELENOGRAD" STORAGE RING

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In 2000, after a long break, works on creation of a technological storage ring complex (TSC) have been renewed in ZELENOGRAD. TSC was developed at Budker INP of Siberian Branch of Russian Academy of Science. It consists of a linear accelerator on the electron energy up to 80 MeV, a small storage ring on the energy 450 MeV, a main storage ring on the energy 2 GeV and two electron transfer lines (TL-1 and TL-2). The Main Ring (MR) with energy of electrons 2 GeV is the dedicated synchrotron radiation source intended for the decision of problem of submicron technologies and realization of various researches in a range of wavelengths of 0.2…2000 Å. Linac was mounted and put into operation during 2000-2002. The circulating electron current was received in small storage ring in 2005. Currently, the assembling of TL-2 is being completed. The inspection of the main storage ring equipment made before is carried out. Besides, a modification of all control and power supply system MR is done and a modern electronic element base will be introduced. The status and the nearest planes concerning TSC main storage ring are described.

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1. INTRODUCTION

Synhrotron Radiation (SR) opened up the possibility 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.

The TSC complex has been developed and manufactured in Budker BINP SB RAS.

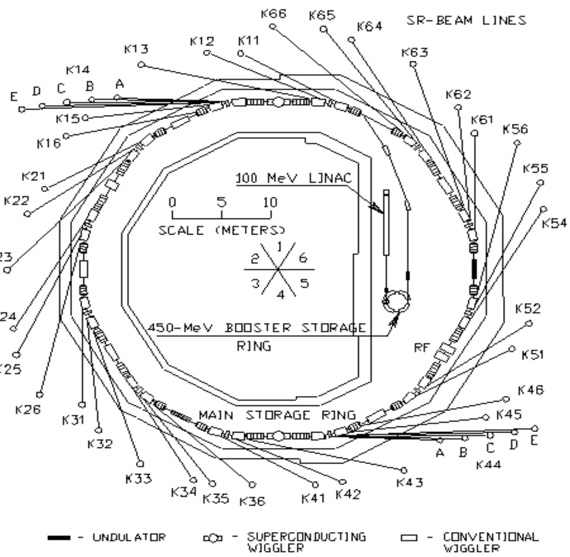

Fig.1. TSC Complex: the Synchrotron Radiation source in Zelenograd

The complex consists of Linear Accelerator (LA) of 80 MeV energy and two Storage Rings: 450 MeV Small Storage Ring (SSR) and 2.2 GeV Main Storage Ring (MSR).

It is meant for generation of bright Synhrotron Radiation (SR) beams in infra-red (IR), ultra-violet (UV) and X-ray areas of spectrum in the wave length range of 0.1…2000 Å.

When the complex of specialized Synhrotron Radiation sources was developed the optimization of magnetic structure parameters has been hold 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 like undulators, mini-undulators and strong field wigglers. It was assumed to have 37 beam line: 20 technology beam from superconducting wigglers line; 10 analytical beam line with use hard SR; 7 analytical beam line with use soft and VUV SR.

Currently main purpose of the project is creation of universal nanotechnology and metrology complex in Lukin NIIFP, Zelenograd in accordance Nanotechnology Federal Programm.

2. INJECTION SYSTEM OF THE MSR

The accepted two-stage injection system is a most efficient variant of the complex structure. Injection part of MR consists of 80 MeV Linear accelerator (LA), 450 MeV small storage ring (SSR) and two transfer lines TL-1 and TL-2.

2.1. LINEAR ACCELERATOR

The 80 MeV Linear accelerator (LA) is an electron source of SSR [1]. It was commissioned at NIIFP of F.V.Lukin (Zelenograd, Moscow) in 2002.

Currently received principle parameters of electron beam at LA output are shown in Table 1[1].

Table 1. *Main parameters of electron beam*

Beam Energy	70 MeV
Energy spread	1%
Pulse beam current	~ 80 mA
Pulse duration	15 ns
Transversal emittance	0.1 mrad·cm
Repetition rate	1…2 Hz

In 2007 a thermostabilization of accelerating structure is planned to be assembled and put into operation as well as to be trained up to 80 MeV.

2.2. TRANSFER LINE TL-1

TL-1 is meant for transfer of electron beam from LA to SSR and for beam emittance matching at LA output with SSR acceptance. TL-1 consists of straight section with quadrupole triplet and an area with two 12° bending magnets meant for parallel transfer of electron beam.

2.3. SMALL STORAGE RING (SSR)

Small storage ring (SSR) is a booster for MSR with the following parameters: single bunch with energy E=450 MeV,electron current I~150 mA and longitudinal size σ_s =30 cm.

Fig.2 shows the SSR preinflector and inflector sections and an area of injection channel. The section I is put under injection septum, RF cavity and beam current sensor. Inside vacuum chamber of II and 1V straight sections, including quadrupole lenses and vertical orbit corrector, there are plates of preinflector and inflector plates. To compensate the chromatism in straight sections II and III the sextupoles are placed. In section IV there is octupole lens to compensate cubic nonlinearity of magnetic field. The extraction septum is placed in straight section III.

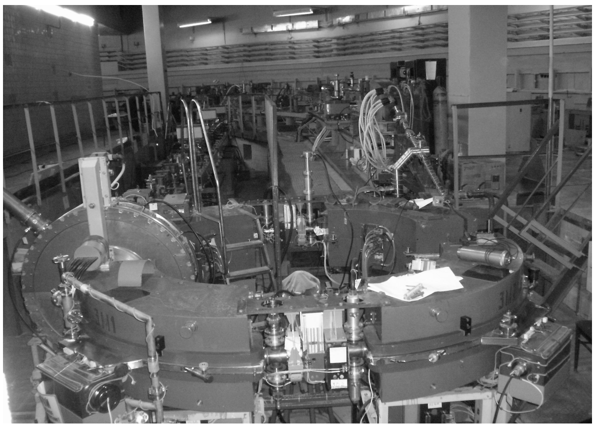

Fig.2. Small Storage Ring

2.3.1. INJECTION AND EXTRACTION OF SSR

Injection in SSR from LA is single-turn and is carried out in vertical plane at 12° angle to median plane. Multiple storage of particles uses pre-kick. Vertical acceptance is A_y= 5.6·10^{-3} cm·rad.

From SR the electrons are also extracted up in vertical plane at 20° angle turn to median plane. Before extraction an orbit is corrected in vertical direction and a beam is moved to the septum magnet. 20 ns duration electromagnetic pulse of deflector plates (inflector in accumulation mode) raises beam path up to the septum magnet aperture. In the septum magnet the extracted electron path is moved into transfer line TL-2. SSR extraction cycle period should be T ~ 0.5 min at circulated beam current I ~ 100…150 mA.

2.3.2. SSR VACUUM SYSTEM

All elements of SR vacuum system are made from stainless steel without any rubber or viton seals. The RF cavity insertion is made from ceramic. Either welded connections or metal seals are applied everywhere. That allows to heat vacuum chamber up to 250ºC.

2.3.3. SSR RF SYSTEM

SSR RF system provides required amplitude 15 kV of RF voltage in cavity. For injection into MR at storage of one RF separatrix it is important that an injected beam was in single bunch. That is why first harmonic of frequency f_0 = 34,59 MHz is used.

Main SSR beam parameters are shown in Table 2.

Table 2. *Main SSR beam parameters*

Energy, E	0, 45 GeV
Circumference, C	8.6832 m
Bending magnet field, B	1.5 T
Relative energy spread, δE/E	3.8·10^{-4}
RF harmonic number, q	1
RF frequency, f_{RF}	34.59 MHz
Field decay index, n	0.5
Betatron numbers: ν_x, ν_y	0.793, 0.895
Relative energy spread, δE/E	3.8·10^{-4}
Horizontal emittance	8.6·10^{-7} mrad
Vertical emittance	8.6·10^{-9} mrad
Radiation damping time τ_x, τ_y, τ_s	7.5, 7.2, 3.4 msec

At the end of 2005 the small storage ring was commissioned, the accumulation mode was reached. That justified that all SSR systems are efficient and there are no bad mistakes. However, at pre-start heating up, in ceramic insertion in cavity straight section a leakage has appeared. We had no reserved ceramic insertion and the production of a new one would take a lot of time. That is why accumulated current was sufficiently limited because of low vacuum characterizing a lifetime of circulating beam. During 2006 a new ceramic insertion has been produced and replaced. SSR vacuum chamber has been heated up and vacuum P = 10^{-6} Pa was reached. Currently, the vacuum chamber is under constant pumping and vacuum is P = 10^{-6} Pa.

Up to the end of 2007 we are planning to accelerate a beam in SSR and extract it into TL-2. During 2008 we are expecting to get all calculated beam parameters.

2.4. TRANSFER LINE TL-2

TL-2 is meant for transfer of electrons from SSR into MSR. It includes:

two 20° bending magnets (4M1 and 4M2) providing vertical parallel transfer of beam three horizontal 20°

bending magnets (4M3, 4M4 and 4M5) for horizontal 60° bend of a beam six quadruples to match the transfer of beam parameters.

Pulse magnet 4M1 with a field of sinusoidal shape is fed from special generator. It is placed in a straight section of SSR. Pulse duration $\tau = 100$ μsec, maximum magnitude B = 3 T, bending radius R = 0.5 m.

Direct current magnet 4M2 is fed from special power supply B-1000 with current up to I = 1 kA. 4M2 – magnitude is B=1.5 T, bending radius – R = 1 m. Magnets 4M3 and 4M4 are the same as magnet 4M2. They are connected in series and fed from the same B-1000.

Pulse magnet 4M5 with a field of sinusoidal shape is fed from special generator. It is placed in a straight section of MSR. Pulse duration is τ=100 μsec, maximum magnitude B=2 T, bending radius R= 0.75 m. To reduce the leakage of magnetic fields into MSR vacuum chamber there is insertion made from "ARMCO".

TL-2 is assembled up to 4M4 magnet. The vacuum chamber was pumped to forevacuum. In the nearest future (October 2007) a beam position sensors and other missing TL-2 elements to the injection MSR septum will be mounted. The vacuum chamber will be heated up in order to start it up by the end of 2007.

3. MAIN STORAGE RING (MSR)

When creating the specialized storages, SR sources, it is most important to reach bright spectral photon fluxes. SR source magnetic structure should provide the possibility to install the undulators and superconductive wigglers in straight sections for storing the electron beam small emittance. In general, the necessity to reach high radiation brighness from bending magnet, high field multipole wiggler and undulator had been revised. Thereupon, the range of optimal behavior of betatron and dispersion functions on azimuths of those SR sources has been found. Optimal amplitude functions of the storage have significantly different behavior on azimuths of bending magnets, wigglers and undulators. Table 3 shows principal parameters of Main Storage Ring the specialized SR source [2].

3.1. MAGNETIC STRUCTURE

Calculated magnetic structure of 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 ν_x=0.73, ν_z =0.74.

Magnetic structure, amplitude functions $\beta_x(s)$, $\beta_y(s)$ and dispersion of MR super period are shown in Fig.3.

The start and the end of super periods are the centers of zero-dispersion sections, which are, mainly, meant for installation of high field wigglers and RF cavities. In the centers of super periods, inside achromatic bend, there are sections where undulators and injection septum magnet may be installed.

The MSR superperiod structure consists of 12 quadrupole lenses and 4 bending magnets. The part of the structure, which includes undulator section, quadrupole lenses F1 and D1 and bending magnets B provides the possibility to obtain achromatic bend and big β_x, β_y, which are optimal for installation of undulator and sextupole lenses to compensate chromatism.

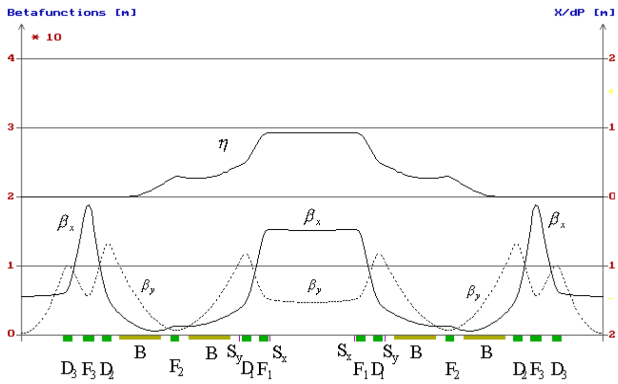

Fig.3. Magnetic structure and amplitude Function of MSR superperiod

Another part, including lenses D2, F3, D3 and wiggler section, provides frequency variations of betatron oscillations, omitting the distortion of achromatic bend. It also provided generation of optimal β_x, β_y in the wiggler straight section. 30º bending magnet is divided into two similar (mirror-symmetric) 15º magnets. The location of F2 quadrupole between 15° bending magnets in focus of achromatic bend system, provides the possibility of easy position control of minimum horizontal beta function (from the right and at the left of lens F2) at reaching the necessary emittance.

Optimal position and minimum value β_{x0} in bending magnet corresponding to minimum emittance $\varepsilon_{xmin,}$ are reached as in achromatic bend scheme, which is realized only by two bending magnets (without separation into two) and by two doublets of lenses F1 and D1. However, at the same time, emittance minimization is practically impossible because the length of undulator section is necessary to be no less than horizontal beta function in it ($\beta_x \sim 20$ m), i.e. the value should be very high. Separation of magnet into two and installation of lens F2 remove this limit, and focusing system inside achromatic bend gets necessary flexibility and allows one to change easily the undulator straight section length in a wide range. In our case, l_{und} = 318 cm is accepted. Besides, there is an opportunity to get injection scheme with two inlet kickers placed on lenses F2 azimuths inside one achromatic bend with betatron phase incursion, equal to π/2, between them. As a result of bending magnet shortening the construction of vacuum chamber is also lightened and SR extraction gets easier.

Values of bending magnet functions β_x and η are close to be optimal. In each bending magnet value β_x is no more than 3.5 meters. In extraction radiation points it is equal to 2.5 and 0.6 meters that provides the radiation extraction from magnet of SR beam with brightness close to maximum.

In a 3 m long straight section, which is meant for placement of super conductive wiggler with high magnetic field, the dispersion and its derivative are equal to zero ($\eta_w = \eta_{w'} = 0$). That is why, when installing the wigglers, there is an addition possibility to reduce emittance.

Horizontal beta-function in the center of wiggler section $\beta_x = 6$ m is sufficiently big. Its value is a compromise between acceptable distinction of dispersion from zero in wiggler section and, from other hand, necessary condition for high brightness at zero angularly. Vertical β_y function is small (~0.5 m). That guarantees a small shift of vertical betatron frequency at installation of high field wigglers. In accordance with calculations, the betatron tune shift introduced by super conductive wiggler with super high field $\Delta\nu_y \sim 5\cdot10^{-3}$. It is enough easily compensated by these local area, without introducing noticeable pulsations of structural functions in the ring.

***Table 3**. MSR Main Parameters*

Energy	E	2 GeV
Perimeter	Π	115.73 m
Super period quantity	N	6
Bending magnets magnetic field	B	0.37; 1.5 T
Quantity of 3 meters long sections		12
Betatron numbers	ν_x, ν_y	7,73; 7.74
Ratio of orbit spatial compression	α	$9.9*10^{-3}$
x, y – chromatism	x_X, x_Z	-19; -20
Horizontal emittance	ε_x	35 nm-rad
Vertical emittance	ε_y	0.35 nm-rad
x, y, s – damping time	t_x, t_y, t_s	4.15;4.3;2.0 ms
Turn frequency	f	2.5905 MHz
RF multiplicity	N	70
RF voltage	U	1200 kV
Current: a) single bunch mode б) multi bunch mode	I	100 mA 300 mA

Depending on tuning the undulator section is characterized by high betatron functions being necessary to get weakly-divergent electron beam $\beta_x = 12…17$ m, $\beta_y = 4…6$ m, and dispersion function is small $\eta_{xmax} = 80…114$ cm.

Each magnetic elements of “Siberia-2” are made from magnetically soft non-laminated Armco iron.

Storage magnetic system includes 24 bending 15° magnets connected in-series. Bending magnets of TSC are of H-type. H-type constructions of magnetic elements of TSC allows making SR beam lines through magnetic yoke without distortion of high quality of magnetic field at working region. The magnet is dismounted in median plane into top and bottom halves. Effective magnetic length is 1457 mm, and iron length is 1446.5 mm.

The bending magnet consists of one main long area and another short area with a field being a quarter from the main one at the edge of the magnet. SR spectrum of 2.5 GeV electrons, at areas with a field *B=1.5T* is $\lambda_c = 1.75\,\mathring{A}$ and *B=0.375T* is $\lambda_c = 7\,\mathring{A}$. The weak field areas adjoin with quadruple lenses D1 and D2.

Such distribution of magnetic field and magnet placement provides spatial radiation separation from a magnet and radiation from wigglers and undulators. Consequently, one provides the decrease of heat flow from orbit area at magnet edges in straight section, where the super conductive systems requiring cooling would be installed.

Magnetic gap between plane-parallel poles of magnetic magnet is equal to 42 mm. At 2.2 GeV energy power consumption of one magnet is 17.6 kW at a current I = 6.3 kA and voltage U=2.8 B in main coil.

For closed orbit distortion in horizontal plane in the areas of weak field magnets the correction coils are provided.

Magnetic system MR includes 72 quadrupoles with dipole and gradient correctors. They joint in 12 triplets, 12 dublets and 12 C-shape quadrupoles. The quadrupoles are separated in 6 families. Each family quadrupoles are connected in series and are fed from power supply IST with current up to 1 kA.

3.2. CURRENT STATUS

All dipoles and quadrupoles Sextupoles and octupoles Multi-pole wigglers and undulators after long storing, are revised in BINP. The revision includes cleaning, electrical tests, magnetic measurements and, if necessary, mechanical modification.

Dipoles will be delivered to Zelenograd in dezember, 2007.

Quadrupoles will be delivered to Zelenograd in march-june, 2007.

Sextupoles and octupoles have been delivered to Zelenograd in June, 2007.

Power supply systems for different magnets such as TPV I=7.2 kA, IST: I=1.0 kA, B-1000: I=1.0 kA, TIR: I=20 A, UM; I=5.0 A. will delivered to Zelenograd in 90th became obsolete. Besides, because of new Complex Control Systems the modification of present and production of new power supply sources is carried out. A part of them will be delivered to Zelenograd and commissioned in 2007 (magnet power supply of injection system).

MSR magnetic system power supply sources are planned to be modified or produced and to be commissioned at TSC in 2008-2009.

Pulse elements power supply (2M2, 4M1. 4M5). The generators for septum 2M2 and 4M1 power supply are assembled and started up at the Complex. The generator for septum 4M5 power supply is being produced. It will be commissioned at the TSC in 2008.

Kicker power supply system. The generators for LA gun and SSR kickers’ power supply were commissioned and are operating at the Complex. The generators for MSR kickers’ power supply are being assembled and commissioned.

RF system is practically newly produced. The spare parts are being purchased and generator is being assembled and produced. Two cavities are manufactured in a workshop. After “cold” and “hot” tests made in BINP, they are planned to be delivered to the Complex at the end of 2008.

Control system. Electronic units have been produced in BINP. They are ready to be delivered to the Complex. SOFT is developed by Kurchatov Synchrotron Radiation and Nanotechnology Center. The mutual cooperation with this Center is planned on a system start up and its adjustment from the beginning of October 2007.

MSR vacuum system.

Dipole vacuum chamber is practically newly produced. Other part of vacuum system are revised and tested. We respect the assembling of vacuum system at the end 2008 – beginning 2009.

Our Plane: Main Storage Ring Commissioning will be in 2009.

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СТАТУС НАКОПИТЕЛЯ ТНК (г. ЗЕЛЕНОГРАД)

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В 2000 г. после долгого перерыва возобновились работы по созданию технологического накопительного комплекса – ТНК, в г. Зеленограде. ТНК был разработан в ИЯФ СО РАН. Он состоит из линейного ускорителя (ЛУ) на энергию до 80 МэВ, Малого накопителя (МН) на энергию 450 МэВ, основного большого накопителя (БН) на энергию 2.2 ГэВ и двух каналов перепуска (ЭОК-1 и ЭОК-2). Накопитель электронов с энергией электронов E = 2.2 ГэВ является специализированным источником СИ, предназначенным для решения проблем субмикронных технологий, а также для проведения исследований в области длин волн 0.2… 2000 ангстрем. Линейный ускоритель был смонтирован и запущен в течение 2000-2002 г. В 2005 г. был получен циркулирующий ток электронов в Малом накопителе. В настоящее время заканчивается монтаж ЭОК-2. Проводится ревизия оборудования БН. Кроме того, проводится модернизация всех систем управления и питания и переход на современную элементную базу. Описывается статус ТНК и ближайшие планы по монтажу и запуску БН.

СТАТУС НАКОПИЧУВАЧА ТНК (м. ЗЕЛЕНОГРАД)

В.С. Арбузов, К.Н. Чернов, А.Д. Чернякін, І.Н. Чуркін, Б.А. Довженко, Е.І. Горникер, А. Кондаков, В.Р. Козак, С.А. Крутихін, Г.Н. Куліпанов, Е.А. Купер, І.В. Купцов, Г.Я. Куркін, А.С. Медведко, Г.Н. Острейко, В.М. Петров, А.В. Филипченко, А.М. Пілан, І.К. Седляров, Г.В. Сердобинцев, С.В. Синяткін, А.Г. Стешов, С.В. Тараришкін, С.С. Васичев, В.Ф. Веремеєнко, В.А. Ушаков, Д.А. Шведов, В.Д. Юдін, А.Г. Валентинов, В.Н. Корчуганов, Ю.В. Крилов, К.Н. Кузнецов, Д.Г. Одинцов, Ю.Л. Юпінов, Н.Н. Грачов, В.П. Храмцов, В.І. Мишачев, Н.В. Спинко

У 2000 р. після довгої перерви відновилися роботи по створенню технологічного накопичувального комплексу – ТНК, у м. Зеленограді. ТНК був розроблений в ІЯФ СВ РАН. Він складається з лінійного прискорювача (ЛП) на енергію до 80 МеВ, малого накопичувача (МН) на енергію 450 МеВ, основного великого накопичувача (ВН) на енергію 2,2 ГеВ і двох каналів перепуску (ЕОК-1 й ЕОК-2). Накопичувач електронів з енергією електронів E = 2,2 ГеВ є спеціалізованим джерелом СВ, призначеним для вирішення проблем субмікронних технологій, а також для проведення досліджень у проміжку довжин хвиль 0.2…2000 Å. Лінійний прискорювач був змонтований і запущений протягом 2000-2002 р. У 2005 р. був отриманий циркулюючий струм електронів у Малому накопичувачі. У цей час закінчується монтаж ЕОК-2. Проводиться ревізія устаткування ВН. Крім того, проводиться модернізація всіх систем керування і живлення і перехід на сучасну елементну базу. Описується статус ТНК і найближчі плани по монтажу і запуску ВН.