THE DEVELOPMENT OF SYNCHROTRON RADIATION SOURCE OF NRC “KURCHATOV INSTITUTE”

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Abstract

Russia`s first dedicated SR source based on electron storage ring Siberia-2 entered service in late 1999, Kurchatov Institute, Moscow. The report focuses on the consumer parameters of an electron beam and the further development of actual SR source, SR beam lines and experimental stations in 2012.

INTRODUCTION

The accelerating complex of the Kurchatov SR source includes: a for-injector - the linear accelerator of electrons on energy of 80 MeV, the small electron storage ring SIBERIA-1 with energy of electrons of 450 MeV, the big electron storage ring SIBERIA-2 with energy of electrons of 2.5 GeV and two electron-optical channels – EOC-1 and EOC-2 [1]. The accelerator complex parameters are specified in Table 1. Official opening of the Kurchatov SR source took place 1.09.1999.

Table 1: Parameters of KSRS facilities

Linac	SIBERIA-1	SIBERIA-2
E = 80 MeV	E = 80÷450 MeV	E = 0.45÷2.5 GeV
I = 0.2 A	I = 0.2÷0.3 A (singlebunch)	I = 0.1÷0.3 A (multibunch)
L = 6 m	C = 8.68 m	C = 124.13 m
DE/E = 0.005	B = 1.5 T	B = 1.7 T
ε_0□300 nm·rad	ε_{x0}□800 nm·rad	ε_{x0}□78÷100 nm·rad
τ_{pulse} = 18 ns	T_0 = 29 ns	T_0 = 414 ns
f_{rep} = 1 Hz	T_{rep} = 25 s	τ =10÷25 hrs
	λ_c=61 Å , BMs	λ_c=1.75 Å, BMs λ_c=0.40 Å, SCW
For-injector	Booster, VUV and soft X-ray source	Dedicated SR source 0.1-2000Å [1]

KSRS FACILITIES WORK

Before 2012 the work of SIBERIA-2 on experiments is carried out with use of SR from bending magnets in energy range фотонов 4-40 keV и спектральных потоках (10^{13}-10^{11}) ph/s/mrad/0.1%BW of photons 4-40 keV and spectral flux (10^{13}-10^{11}) ph/s/mrad/0.1%BW during week runs in a round-the-clock mode. Within one week 9 working 12-hour shifts are presented.

But, a regular work of X-Ray structure analysis station (RSA) with SR of 7.5T wiggler`s is planned (beamline 1.4-3, 17 mrad) starting from October 2012.

Diagram in Fig.1 shows the integral time devoted for SR experimental work at Siberia-2 in 2000 – 2011 years. Table 2 presents statistic of SR source Siberia-2 work at experiment in the first half of 2012. Note that in 2012 the SR source spent relatively much time in standby and adjustment mode due to stops for the firms which work according contracts (opening shielding walls, new beam lines installation, etc).

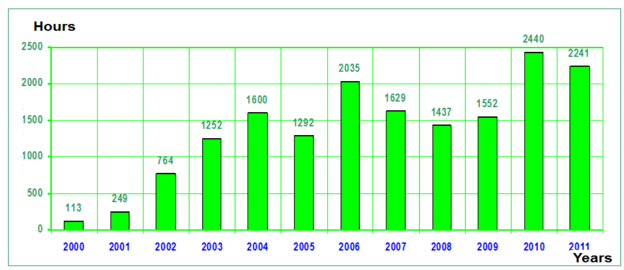

Figure 1: Experimental time at Siberia-2 in 2000-2011.

Table 2. Statistics of Siberia-2 on July 2012.

Parameter	SIBERIA-1	SIBERIA-2
Total working time, hrs : min	2371:18	2371:24
Experiment mode		
Duration, hrs	43	1074
% of total working time	2%	45%
Maximum current, mA	300	130
Average current, mA	116.6	46.0
Full integral, A-hrs	348.3	1046
One half of year 2012, A-hrs	5.0	49.3
Lifetime, hrs (100 mA)	1:56	38.5
Lifetime, hrs (50 mA)	1:11	51
Injection	10%	5%
Adjustment	34%	24%
Mode on duty	54%	25%

DEVELOPMENT OF KSRS ON 2010-2012

The works on modernization of systems of actually accelerating complex during 2008-2010 were in detail reported at conference RUPAC 2010 [2].

The purpose of works on 2010-2012 is both modernization of the existing equipment of a SR complex, and introduction in a system of new development.

ISBN 978-3-95450-125-0

Nanosecond Pulse Generator

During 2011-2012 the pilot copy of the nanosecond pulse generator on pseudo-spark switches (thyrotron TPI1-10k/50) for Siberia-2 injection system is developed and made in KCSR. The first tests with an electron beam were carried out when giving on short-circuited plates of an inflector of impulses of a current (≤3kA) with a semi-sinusoidal form of adjustable duration (100-200 nanoseconds) and a jitter <1ns. Such generators will allow refusing from the use of the high-voltage gas-filled electric discharge devices and from the forming lines. They promise stabilizing the homogeneity of the filling both in multibunch and in single bunch modes of operation during injection to Siberia-2. Work proceeds in a background mode.

Shortening of an Electron Bunch in SIBERIA-1

In 2008 on the SIBERIA-1 a new pulse output septum – magnet with more homogeneous distribution of a magnetic field was established. The increase in ejection factor of an electron current from SIBERIA-1 in EOC-2 to 70 % was received as a result. The following step on increase in ejection efficiency of electrons to SIBERIA-2 was made in 2011 when the RF generator of Siberia-1 was powered for the purpose of increase in accelerating tension at RF resonator of 34.5 MHz. from 15 kV to 30 kV. Now less than in 0.1 second before release of electrons with energy of 450 MeV the RF generator current is charply increased and, at the RF cavity invariable tune, the electric voltage on the cavity jumps from 15 kV to nearly 30 kV, leading to bunch shortening to $6\sigma \approx 130\text{cm} < \lambda_{181\text{MGz}} = 165.6$ cm. This action stabilizes a capture percentage in Siberia-2.

SYBERIA-2 RF System

At the end of 2009 on a ring of SIBERIA-2 three bimetallic resonators (the walls:7 mm of stainless steel and 8 mm of copper, diffusive welding) were installed on purpose to keep possibility of work with 7.5T wiggler causing increase of energy spread in a bunch for 30 percent. Now RF system consists of two RF lines, everyone includes RF generator on 200 kW on two tetrodes of the GU-101A type, a wave guide and 1 or 2 RF 181 MHz cavities with the feeders. The new set of parameters of SIBERIA-2 and RF system is listed in Table 3 [3].

Table 3. SIBERIA-2 and its RF parameters

Electron energy	E_{MAX}	GeV	2.5
Beam current	$I_{B\,MAX}$	A	0.29
SR losses from: bending magnets; bending magnets and SCWs	ΔE_{BMs} ΔE_{BM+WIG}	keV/ turn	681 1021
Accelerating voltage	$2U_1+U_2$	kV	1500

Further increase of the SR source work reliability connected with a transfer of Siberia-2 RF generators output cascades to new type of generating lamps of the TH781 type (powerful tetrodes), let out by THALES firm (France), is planned for 2012-2013. Thanks to pirographite grids they have higher reliability and a warranty period of service (3500 hours) in comparison with tetrodes GU-101A. The maker of the lamps assumes that on frequency 181 MHz , at RF capacity of 150 kW, the lamps will work not less than 7000 hours.

Delivery of TH781 lamps in KCSR will be executed on October, 2012. To minimize costs of their installation, the cases of the powerful output cascades of the RF generators, designed under lamps ГУ101А, will be modified with keeping the former principles of the capacities addition, modules of control and communication with loading (under the contract with BINP, Novosibirsk). Respectively, we are expected by the researches connected with setup of the new RF generators cascades and paths for steady work with a electron beam.

Increase of Electrons Lifetime in SIBERIA-2

On injection to SIBERIA-2 in a multibunch mode with a typical current in one bunch 3-4 мA the lifetime doesn't exceed 30 minutes. Mainly it is defined by Tuschek's effect. The most acceptable method to increase the lifetime at low energy is control of betatron oscillations by means of two skew-quadrupoles [4]. As a result, on injection energy the lifetime grew by (30-40) % depending on a current in one bunch. A speed of accumulation of electrons increased also. The fast and reliable algorithm of reorganization of magnetic structure was developed for ramping the energy in SIBERIA-2 [5] and the lifetime in the course of energy ramping to 2.5 GeV was increased. All process of acceleration borrows 2min.40s, at the losses in a beam current, generally on the energy below 1 GeV, which are not exceeding 2-3 %. During energy ramping the changes of betatron tunes from a working point of Qx = 7.773, Qz = 6.701 don't exceed the value ΔQ=0.015. The most dangerous resonances leading to losses of a beam are the resonances of the 4th order 2Qx + 2Qz = 29 and 4Qx =31. The greatest changes of betatron tunes occur at approach to 2.5 GeV and a stop of energy ramping.

New System "Orbit" at SYBERIA-2

In 2012-2013 24 pickups which are available on a ring of Siberia-2 will be supplied with the new high-precision electronic equipment and software product for measurement of cross-section coordinates of an equilibrium orbit (KCSR and LIBERA, Slovenia). Spatial resolution at measurement time more than 5 milliseconds for an average current of a beam 5-300 мA makes 1 micron.

Feed-back Systems at SYBERIA-2

Now on the SIBERIA-2 we observe mutual influence of control systems of two RF generators at each other through an electron beam. It leads to unstable work of RF

ISBN 978-3-95450-125-0

generators and to the electron current losses. The losses depend on a number of bunches. The quantity of particles in separate bunches is modulated according to the excitation mode number of synchrotron oscillation, see Fig. 4.

In 2012-2013 on SIBERIA-2 the Bunch-by-Bunch feedback system for suppression the instabilities in transverse and longitudinal directions (KCSR and LIBERA, Slovenia) will be established.

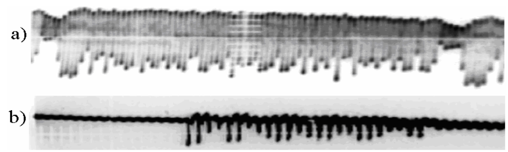

Figure 4: Modulation of particles in bunches at different fillings because of losses at an excitement of a collective mode of instability.

In the Fig. 5 the scheme of feedback for SIBERIA-2 is presented. As a kicker for suppression of coherent sinchrotron fluctuations small special RF cavity with own frequency of 950 MHz and a quality factor of 10 will be introduce at the straight section of ring. The existing strip lines will be used as kickers for suppression of coherent betatrone oscillations in X- and Y- plane. Also digital electronics, broadband amplifiers (25 W and 100 W) and a pickup - electrodes, phase detectors, the modulator, RF control are here entered.

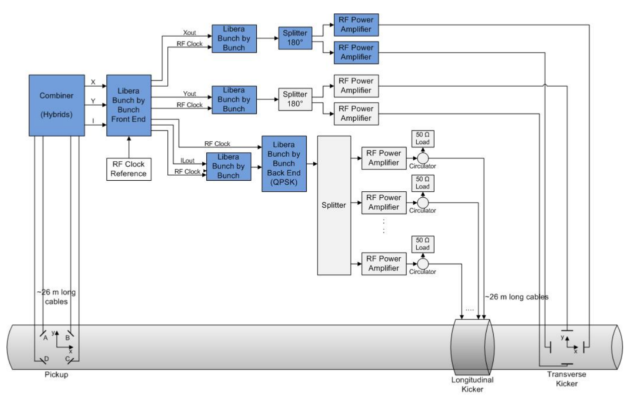

Figure 5: The scheme of BbB transverse and longitudinal feedback for SIBERIA-2.

New Station of Optical Observation [6]

By April, 2013 on Siberia-2 the special vacuum SR beam line will be mounted to release a visible range of SR out of limits of shielding wall of Siberia-2 storage ring where an optical bench with electronics of optical supervision (a CCD - matrix, φ - dissector, the 2-slit interferometer, the photomultiplier, TV) with high spatial and temporary resolution will be installed .

In the Fig. 6 the scheme of optical station is shown. The station of optical supervision includes automatic system for turn-by turn registration of a cross-section profile of a bunch. It is intended for measurement X - and Y - particles density distributions in chosen bunch, frequencies of synchrotron and betatron oscillations, and also for research of dynamics of a bunch form in chosen separatrix on one (from 3) chosen coordinate.

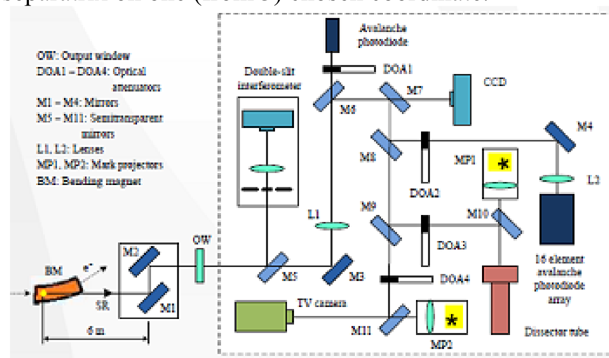

Figure 6: The scheme of optical station

The system turn-by-turn registration includes a lens and a linear detector based on 16 avalanche photo diodes. The signal of each photo diode is integrated and transferred on 12-digit ADC, having frequency of digitization of 50 MHz. The internal buffer memory accumulates results of measurements of ADC and allows to investigate turn-by-turn profiles of a bunch for long time (hundreds thousands of turns).

The station of optical supervision will be located outside of biological protection of storage ring. The work is conducted by KCSR and BINP.

New Power Supplies for Magnetic Correctors

In 2012 KCSR began a replacement of power supplies of the correcting magnetic elements at accelerator complex by the new more exact sources developed by "Marafon" firm (Moscow). At the first half-year of 2013 the all set of the 269 bipolar and unipolar sources (current stability 5E-4) will operate with a new control system and computer programs. Now the tests of pilot samples of sources on 6 A and 20 A are carried out. An installation of new sources at Euro-racks is in progress.

New Control System (KCSR, RT-Soft)

Upgrade of CS consists in changeover of the old equipment of CAMAC on trunk - modular hardware in the VME standard and the organization of new architecture.

In 2010 purchases of the modern electronic equipment are realized, the specialized laboratory of automation of a complex which task includes, in particular, application software development, start into maintenance and maintenance of the difficult equipment in working condition [7] is created.

CS is conditional subdivided into the upper and lower levels, server level and the periphery.

The lower level of CS realizes collection of diagnostic information and execution of control algorithms by executive systems of accelerator complex. It includes trunk-modular equipment in the VME standard and controlling equipment with the built-in processors

ISBN 978-3-95450-125-0

working under control of OS of the Lynx OS type. This equipment is connected to server level Ethernet or CAN communication lines.

Server level of CS includes application servers and the server of management system of a database (DBMS). At this level it is implemented: general control algorithm and UNK monitoring; a data interchange with processor modules of the VME standard, with CAN controlers and with an automated workplace of operators; recording of sessions of operators; information storage in DBMS; information representation on requests of users; self-diagnostics of operation of CS.

The top level of CS includes an automated workplaces of operators and other users. The full-function monitoring system and controls - CitectSCADA will work at the top level. The software of CitectSCADA allows to provide: visualization of processes, automated workplace control, tracing of systems in real time in a graphic look and access to contemporary records, preparation of the detailed reports, execution of the sub-programmes developed on CitectVBA and CiCode.

Geodesy (KCSR, "Neva Technology")

In 2011-2012 operations on creation of a high-precision geodesic network on the basis of the acquired exact equipment of type the laser tracker and specially set geodesic markers in the experimental hall of Siberia-2 are carried out for the purpose of an exact exhibition of elements and axes of being created new SR beamlines outside of bioprotection walls. Now the geodesic network in the experimental hall is integrated with a geodesic network of Siberia-2 storage ring tunnel so that they have a single system of coordinates.

NEW STATION AND INSERTION DEVICES

Bending Magnet SR Stations

Now installation ("NT-MDT", Zelenograd) of three experimental stations (hutches and optical components) and the three SR beamlines from 1.7 T bending magnets of SIBERIA-2 comes to an end: "PES" – Photoelectronic spectroscopy - K6.5, "PHASE" - X-ray precision optics-2 - K2.3, "NANOFAB-2" – research of micro and nano-electro-mechanical systems (MEMS and NEMS) - K2.6... Qualitative difference of these beamlines and stations from the already existing is that actually disappears concepts of separate station and the separate beamlines. Components of optics are distributed on all length of SR beamline. For example, the mirrors of complete external reflection are inside bioprotection space, at distance of 5-6 m from a radiation point, the blocks of monochromators at distance of 24-25 m whereas samples are at distance to 40 m from SR source.

Work with 7.5T SC Wiggler [2]

The SR from 7.5T (19+2) poles SCW was deduced for the first time on three SR beamlines in the experimental hall of SIBERIA-2 in November, 2009. In the Fig. 7 TV-images of SR from SCW on the luminescent screens set at end faces of the three SR beamlines are shown.

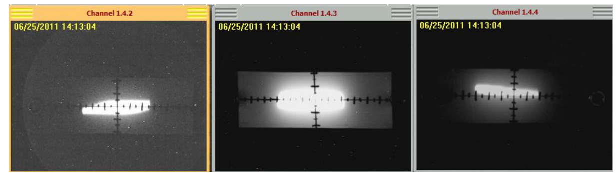

Figure 7: SR of 7.5 T SCW on an output of three beamlines (-13 mrad, 0 mrad, 17 мрад) in the experimental hall of SIBERIA-2.

Then, as a result of superconductivity loss in SCW, there was a collapse of the thin-walled copper liner (the vacuum chamber inside a cryostat) to loss of a vertical aperture. In June, 2011, in case of next superconductivity loss, there was a collapse of already next new and harder liner No. 2.

Figure 8 shows a wavy deformation of the liner No. 2 surfaces in the liner central part especially, repeating the period of a magnetic field of SCW with a longitudinal shift relatively to pole centers with maximum fields on a quarter of period.

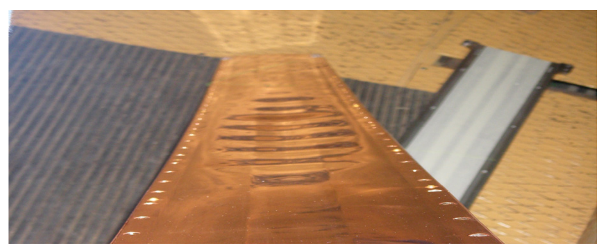

Figure 8: Deformation of walls of the liner No. 2.

After manufacture of the liner No. 3 and two new power supplies (the third pair), in December of 2011 their joint tests were carried out with SCW out of a Sybiria-2 ring, but with failure of superconductivity in the field of 7.5 T.

It was clarified that the current instability of power supplies led to overvoltage on the high-inductive windings and to inadmissible throws of a current. The current proceeding through one of sources, reached 350A instead of 240A, necessary for field 7.5T creation, as provoked failures.

Direct measurements of a vertical aperture of the liner No. 3 showed that deformations after failure remained within 0.1 mm. The decision about SCW installation with the liner No. 3 on a ring of Siberia-2 was made. By May of 2012 two new power supplies were made once more, the beamline K.1.4-3 (17 мрад) was joined with RSA station and continued to the double - crystal monochromator.

Input of SR in optical hutch of RSA stations was made on July 5, 2012. The image of SR at RSA station was observed by means of TV-cameras and the luminescent sensors located after the first optical mirror before and

ISBN 978-3-95450-125-0

after the double-crystal monochromator, adjusted for the SR wavelength of 1 Å, see Fig. 9.

Figure 9: A SR from SCW at RSA station. At the left - before, on the right – after the monochromator (1 Å).

Within the program of tests the failure of a superconducting condition of a wiggler in the field of 7.5 T was carried artificially out. The test of the wiggler windings by means of switching on of low currents in the wiggler just after failure showed that windings are serviceable and returned to a superconductivity condition.

The vertical aperture measurement of a liner by means of distortion of an electron beam equilibrium orbit («bump») showed that residual deformation of the liner did not lead to reduction of a vertical aperture. After summer vacations, 13.09.2012, regular operation on the filling of a liquid helium in the wiggler was executed. The sc wiggler magnetic field was increased up to 4.5T to reduce a magnetization of wiggler poles which was happened after last failure. Next work with the wiggler will be devoted to the degassing of the first SR absorber (about 36 kW of X-Ray power at electron current of 100 mA) and the increase of the operating electron current with sc wiggler switched on.

Creation of 4 SR Stations in 2013-2015

According to the Experimental Program in the direction 2 in KCSR the installation in an experimental hall of head samples of new generation experimental stations for complex researches in the field of convergent nano- bio- info- cognitive sciences and technologies is considered. Among them: station of low-angular diffraction (LAD), station of X-Ray absorbtion spectroscopy (EXAFS), station of a protein crystallography (Protein-2), station for substance research in extreme conditions (SEXC).

The Planned SC Wigglers on SIBERIA-2

The KCSR starts a creation of two new superconducting wigglers with a field of 3T at equilibrium orbit with critical wavelength of 1Å (additional to available 7.5 T sc wiggler) and their installation on the Siberia-2 storage ring in 2014. Key parameters of the new SC wigglers are given in Table 4 with a field 3T at energy of electrons E=2.5 GeV and a current of electrons of I=0.1 A.

High-intensity radiation of these wigglers will be used in «Experimental station for substance research in extreme conditions» - K2.4 and at station «A protein crystallography-2» - K3.4.

In comparison with intensity from a wiggler with a field of 7.5 T, the wiggler with a field of 3T has an advantage in a spectral interval of 5-30 keV photon energy.

Table 4. Project parameters of 3 T SCW.

Beamline	K2.4, K3.4
Electron energy, GeV	2.5
Pick magnetic field at axe, T	3.0
Photon critical energy, keV	12.48
Photon energy spectrum, keV	5-40
Magnetic period, mm	44
Angular divergence o SR, mrad	±2.77
Number of poles: main/lateral	69/4
Intensity of SR at ε_c=12.48 keV, ph/s/mrad/0.1%BW (I = 0.1 A).	$3*10^{14}$

CONCLUSION

We are sure that continuous efforts in the solution of the scientific and technical problems rising before employees of KCSR, will lead to high-quality improvement of the Kurchatov Center of Synchrotron Radiation.

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ISBN 978-3-95450-125-0