KURCHATOV SYNCHROTRON RADIATION SOURCE FACILITIES MODERNIZATION

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Abstract

Kurchatov Synchrotron Radiation Source (KSRS) operates in the range of SR from VUV up to hard X-ray. Technical modernization of KSRS systems is under way. It includes a replacement of the power supplies and the nano- and micro-second generators by the new ones, the installation of the new third RF accelerator cavity on 2.5 GeV storage ring SIBERIA-2. The projects of the feedback system for the longitudinal coherent multi-bunch instabilities dumping and of the new sensitive electronics for pick-up stations on Siberia-2 storage ring start in 2010. Three 7.5 T wiggler beam lines were mounted and tested with SR beam in December 2009. The 7.5 T (19+2) poles SC wiggler and new 3 RF cavities are doing the KSRS spectrum harder and intensive. The program tools for KSRS operation are introduced in accelerator control system with a new electronics. The new scheme of top-up energy injection placed outside of Siberia-2 storage ring tunnel is carried out. The report describes a statistics works and plans on KSRS facilities.

INTRODUCTION

The accelerator complex of KSRS consists of the linear accelerator and two storage rings [1]. Main parameters of the KSRS accelerator facilities are shown in Table 1.

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
T = 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
Forinjector	Booster, VUV and soft X-ray source	Dedicated SR source 0.1-2000Å [1]

Possible number of photon beam lines from BMs equals to 24, SR sources like SC wigglers and warm wigglers (undulators) are planed to offer 6-8 SR beam lines from IR to hard X-ray radiation.

KSRS FACILITIES WORK

The work of SIBERIA-2 on experiments is carried out with use of SR from bending magnets in energy range 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.

Table 2 shows the integral time devoted for SR experimental work in 2005 - 2009 years. Fig.1 contains some statistics of the time which was spent on experiment, injection and tuning of SR source.

Table 2: SR Experimental time in 2005-2009 years

	2005	2006	2007	2008	2009
Siberia-1: experiment, hrs	238	236	205	471	634
Integral, A-hrs	16.1	21.1	13.4	41.7	67.4
Siberia-2: experiment, hrs	1292	2035	1629	1437	1527
Integral, A-hrs	94.9	165.5	126.2	56.3	77.5

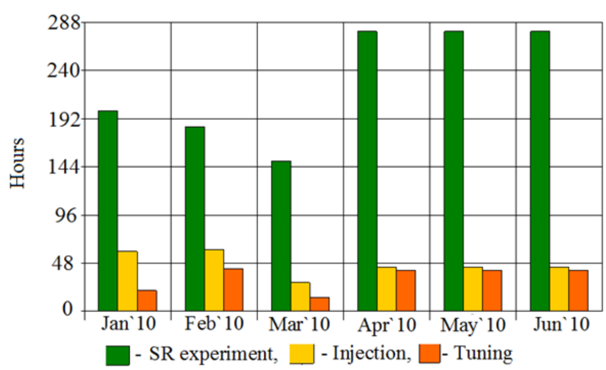

Figure 1: The Siberia-2 work in 2010.

MODERNIZATION OF 2008-2010

New septum-magnet of Siberia -1(KCSR-INP)

The new pulse septum-magnet was installed with aim to increase the effectiveness of electron beam ejection from Siberia -1 into the electron transport line - ETL-2. The new septum-magnet is the modified version of the old one that worked during previous 8 years. It has more homogeneous magnetic field distribution. The results are obtained: stable control of the pulse generator of the septum-magnet, an increase in the coefficient of the release of electron beam from the Siberia-1 storage ring into the ETL-2 up to 70%.

New SR beamline at Siberia-1 (KCSR – NIIOFI)

SR from 3[d] BM of Siberia-1 was conducted in VUV experimental hall after the completion of mechanical and vacuum works on the new beamline D3.2. First metrology experiments were made by NIIOFI and KCSR staff.

RF system of Siberia-2 upgrade

The RF system upgrade was target to increased reliability of the machine operation and to adapt Siberia-2 storage ring to operate with new high magnetic field sc wigglers. Now RF system of Siberia-2 has two channels. Each channel includes 200 kW RF generator (with two GU-101A thetrodes), a waveguide and one or two 181 MHz cavity with own feeders. Three bi-metal cavities (7 mm of stainless steel and 8 mm of copper joint together by diffusion bonding) were installed in the storage ring upon completion of the upgrade. Initially, on December 2007 one old cavity has been replaced by a section of two new cavities. Second old cavity was replaced by a single new bi-metal cavity on October 2009.

So total accelerating voltage is increased up to 1.5 (1.8 MV max). New set of parameters of the storage ring and its RF system is listed in Table 3.

Table 3. Parameters of Siberia-2 and its RF system [9].

Parameters of the Siberia-2 storage ring	Energy of electrons	E_{MAX}	GeV	2.5
	SR losses with BMs and wigglers	ΔE_{BMs} ΔE_{BM+WIG}	keV/ turn	681 1021
	Beam current	$I_{B\ MAX}$	A	0.29
	Total accelerating voltage	$2U_1+U_2$	kV	1500
First RF channel : 200 kW generator, two cavities (№1, №3)	Accelerating voltage	$2U_1$	kV	820
	Shunt impedance	$2ZT^2$	MOhm	8.6
	Power dissipated in the cavities	$2P_1$	kW	39
	Power transferred to the beam	$2P_{1b}$	kW	157
Second RF channel: 200 kW generator, one cavity (№2)	Accelerating voltage	U_1	kV	680
	Shunt impedance	ZT^2	MOhm	4.3
	Power dissipated in the cavity	P_2	kW	54
	Power transferred to the beam	P_{2b}	kW	139

A new 2 feeders connected with the waveguide of RF generator №1 deliver RF power to the lateral cavities (№1 and №3). The middle cavity (№2) is fed by the RF generator №2, see Fig.2.

At the moment we observe the mutual influence of two RF generator control systems through the electron beam which leads to unstable operation of the RF generators.

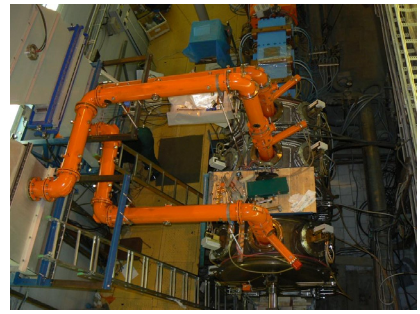

Figure 2: New cavities and feeders at SIBERIA-2 ring.

According to a simulation, the stability will grow with tuning the RF feeders and the waveguides at a wavelength of (n+1/8)l. We plane to do it to the end of 2010.

The synchrotron oscillations collective modes appear after injection of first four or five bunches. The energy ramping of the electrons with current in many bunches exceeding 150 mA is characterized by synchrotron motion in coherent modes and possible losses of the beam part. The losses depend on the number of bunches and modulate the particles numbers in bunches correspondingly with the synchrotron mode number, see Fig.3.

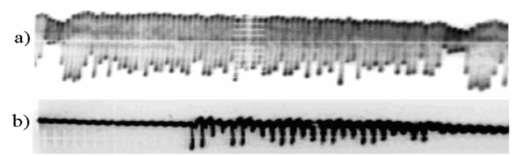

Figure 3: The modulation of bunches with different filling due to collective mode instability losses.

The decision was made to carry out “Bunch-to-bunch longitudinal feedback” to dump the coherent synchrotron oscillation. It will include a wide-band cavity as a kiker, a wide-band pick-up electrode, a phase detector, a modulator, RF control electronics, a wide-band power amplifier.

New nanosecond generator (KCSR)

The prototype of new low voltage sin-like pulse nanosecond generator with 100-200 ns semi-period was created at a base of the pseudo-spark thyratron “ТПИ1-10К/50”with the cold cathode. Maximum anode amplitude is of 25-30 kV. It was successfully tested with the electron beam. The short-circuited plates of the Siberia-2 inflector were switched on as parallel electrical loads of the new ns generator (<1.5kA, 14 kV). In result, the high temporary stability of capture of electrons was reached in the regime of injection in Siberia-2 with high efficiency (up to 70- 75%). The features of new device are low voltage, absence of spark discharge and a work only with magnetic field between the kiker plates. It will be a real alternative to high voltage existing inflector and preinflector nanosecond generators of Siberia-2, which work on the electric spark dischargers.

New SR beam lines from BMs of Siberia-2

Currently under construction are 3 experimental stations and 3 SR beamlines from the 1.7.T bending magnets of Siberia-2: "PES" - Photoelectron Spectroscopy (PES, ARPES, NEXAFS) - K6.5, "PHASE"- X-Ray precision optic-2 - K2.3, "NANOFAB-2" – micro- and nano-electro-mechanical systems researches (MEMS and NEMS)- K2.6. These SR beamlines and experimental stations are producing with a firm "NT-MDT", Zelenograd.

New SC wiggler beam lines

We note the production and the consequent mounting of wiggler`s beam lines elements were effectuated according to KCSR`s drawings with the help of a firm «Megaterm», Briansk...

In the first half-year 2009 the installation of three SC wiggler`s beam lines elements was first executed inside the tunnel of Siberia-2, then they were conducted through the shielding wall and installed in the experimental hall. A specially designed 100 kW SR absorber–distributor was mounted near the ring of Siberia-2. Inside its vacuum volume it contains one stationary and three movable absorbers for each of three separate SR beam lines. Before 100 kW absorber the DU250 shatter was posed for the separation of the vacuum systems of the X-ray beam lines and Siberia-2. These works were alternated with the work on SR experiments.

In September - October 2009, the work was carried out with the opening of the vacuum chamber of Siberia-2. A new camera with three SR absorbers to limit sc wiggler`s SR divergence was installed in the triplet following 7.5T wiggler. A refinement was also made of the existing pumping unit and diagnosis (PDU), located after the first bending magnet (following the triplet). It was introduced in PDU volume two immobile and single movable absorbers to protect the DU250 shatter against SR, coming from the bending magnet. In addition, engineering equipment, visualization elements of SR and TV monitor were mounted on the beam lines.

INSERTION DEVICES

Works with 7.5Tt SC wiggler

Project SC wiggler parameters are presented in Table 4.

Table 4: Project SC wiggler parameters at 2.5 GeV

Max. field, T	3-7.5
Period, mm	164
N_{poles}	19+2
Elliptic liner, Cu. V*H, mm	13*120
$E_{ph\ crit}$, keV	31.2
Flux, ph/s/0.1%BW	10^{14}-10^{12}
Working spectrum, keV	5-200
Θx max, mrad	± 23.5
Energy loss/turn, keV	365
P_{tot} (100 mA), kW	36.5
Coils	NbTi

First run of SC wiggler was carried out on 2008, June, 7 with the 3 T magnetic field [2].

In November 2009, after the mounting of 3 wiggler beam lines was completed the vacuum conditions in Siberia-2 for the work with the electron beam were restored. The control code was debugged for new bipolar power units of wiggler and the ramping of magnetic field up to 7.5T was accomplished in the automatic regime. The measured shifts of betatron tunes have coincided with theoretical ones with good accuracy, Fig.4.

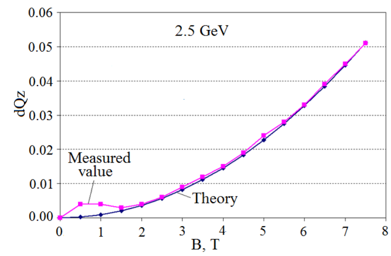

Figure 4: Measured and theoretical vertical betatron shift vs SCW magnetic field amplitude.

Hard component of SR was observed in an experimental hall with a TV camera at luminescent screens fixed on flanges, closing the ends of each of 3 tubes, Fig.5.

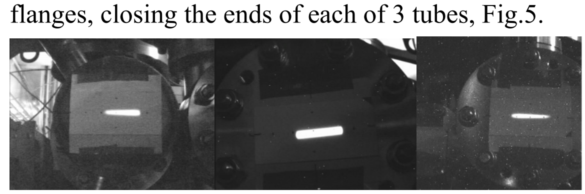

Figure 5: X-Ray beam from 7.5T SCW at output of three beam lines in the experimental hall of Siberia-2.

Measurements of position of x-ray beams relative to axes of channels and its operative adjustment have been simultaneously implemented. Besides, the card of radiation fields has been measured in an experimental hall with the deduced X-ray beams.

Unfortunately, in December 2009 the breakdown of superconductivity has occurred in the coils of the wiggler magnets at 7.5T. Under the action of resulting ponderomotive forces, the liner of wiggler - intra-vacuum thin-walled copper tube of almost elliptical cross section - collapsed, completely blocking the aperture. Therefore, the wiggler was evacuated from the ring of Siberia-2 and replaced by a spacer. In June 2010 new modified more durable liner was manufactured (BINP, Novosibirsk) and wiggler was again put on the storage ring in early July 2010.

In July-September, the vacuum chamber was degassing by means of SR. Last decade of September, after collecting the integral 2.1 A-hrs of electron current, Siberia-2 works at 2.5 GeV with 40-50 mA electron current and a lifetime of 2-4 hours. We plan to continue the work with the wiggler in October 2010.

New IDs planned at Siberia-2

The planned scheme of the insertion devices location on the Siberia - 2 storage ring is shown in Fig.6. Eight IDs are to be installed, among them 4 superconducting, 3 normal conducting wigglers and one mini-undulator. Besides that one photon line of infra-red (IR) edge radiation (ER) will be taken out [3,4]. IDs approached parameters are given in the Table 5.

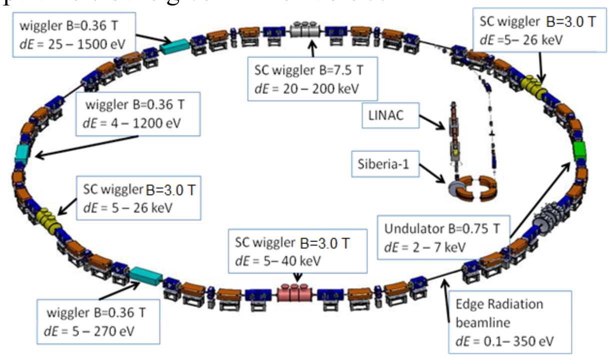

Figure 6: Plan of IDs location at Siberia-2

Table 5. Main parameters of planed insertion devices

IDs	Bmax T	λu, mm	N per	Eph	SR station, planed
1 SCW	7.5	164	10	4-200 keV	RSA, RS-MCD, Hard X-Ray
3 SCW	3.0	44	35	5-40 keV	Belok-1, Belok-2, Lengmuir-2, Standing X-Ray
3 NCW	0.36	80	51	5.5-270eV	PES microscop, PES-SH Resol., Spectro-Lumi, VUV, MR
Mini-U	0.75	7	300	2-7 keV	1.3 GeV: X-Ray holography
IR ER	-	-	-	0.1-350eV	IR, VUV, Soft-X-Ray

New experimental stations on 7.5T SCW

Now there is a progress in the creation of next 3 new experimental station based on SR from 7.5 T SC wiggler:

1. EXAFS/XANES and X-ray Magnetic Circular Dichroism (XMCD): q= (13.3 ± 1) mrad, λc = 0.5 Å, P = 760 W/mrad – beam line K1.4.2;
2. Hard X-ray: λc=0.4Å, P=940 W/mrad, q= (0 ± 1) mrad – beam line K1.4.3;
3. X-ray structure analysis-RSA: q=(-17 ± 1) mrad, λc=0.58 Å, P = 650 W/mrad – beam line K1.4.4.

Here the SR power data correspond to 100 mA current and 2.5 GeV energy of the electron.

IMPROVEMENT OF BEAM PARAMETERS

Ultimate goal of improvements of parameters of electron and photon beams is the increase of brightness, spatial and time stability of SR source.

Diagnostics and control system [5]

- A new electronics and computer control codes were run at Siberia - 1 and Siberia – 2 for betatron tunes measurement. The betatron spectra are measured and demonstrated on operator monitor with high precision.
- A new NMR probe with auxiliary electronics and control code was installed in the calibration bending magnet of Siberia-2. New electronics serve as a part of feedback system of electron energy stabilization scheme.
- A new electronic devices (crate controllers K167), computer control codes (miniMODUL167 processor and ARTX-166 real time OS) and operator interface were elaborated and run. On the base of CC K167 and managing server of class Pentium IV several application were improved: the measuring of an electron current value in Siberia-1 and a transverse beam position in the electron transport line ETL-2 became rather simple and reliable; the modernization of synchronization system and control system of the pulse power supplies of accelerator complex were realized; new control system of Siberia–2 RF generators is developed and successfully introduced; management of power supplies of the quads and steering magnets of Siberia – 2; new operational control software and the experimental data archives in on-line mode are started in routine work.

An increasing of electron life time at Siberia-2

The lifetime at injection energy of 450 MeV is much less - not more than 30 min in single-bunch mode with a typical current in one bunch 3 - 4 mA. It is mainly determined by Touschek effect in the presence of limiting the horizontal aperture. According life time studies we have found that the most accessible method to increase the lifetime was the control of betatron oscillations coupling at low energy.

The betatron coupling was adjusted by two families of skew-quadrupole. As a result, at the injection energy an increase of lifetime was reached from 30% to 40% depending on the number of particles in one bunch. As a consequence the storage rate of electrons was increased also. Besides that, the lifetime was increased in process of the energy ramping, thus reducing the loss of current during the ramping process from 5 - 6% to 1.5 - 2% .

The lifetime of the electron beam at 2.5 GeV in Siberia-2 storage ring is determined by the vacuum conditions and is now more than 15 hrs at a current of 100 mA.

Beam lifetime $\tau(t)$ at 2.5 GeV depends on time t as follows: $\tau(t)^{-1} = \tau_0^{-1} + C \cdot I(t)$, where $I(t)$ - electron current, τ_0 - lifetime when the current approaches to zero, C - constant, τ_0 is determined by the level of vacuum in absence of the beam. The second term can be determined by the effect of Touschek or by a gas desorption stimulated by SR from the walls of the vacuum chamber. In our case, the second mechanism is running, since the values τ_0 and C depend on the collected current integral at 2.5 GeV (see Fig.7).

Let's note, that after closing the vacuum chamber, for the achievement of life time of 12 hours at the 100 мA electron current it was required to collect an integrated doze of 16 A*hrs, that is 10 times less, than it was required at the very beginning of SIBERIA-2 work with electron beam.

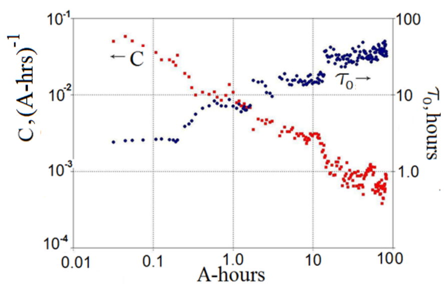

Figure 7: Parameters of τ_0(in blue) and C(in red) vs collected integral of electron current at 2.5 GeV.

MODERNIZATION OF SR SOURCE

Top-up energy injection with synchrotron [7]

In KCSR the Project of technical upgrade of accelerator complex as SR source was developed [6]. The purpose of the Project is to create SR source of 2.5÷3 generations on the base of existing accelerator complex. This will increase the spectral brightness more than in 30÷100 times in comparison with the realized project. To reach this aim means to develop the new optical structures for SIBERIA-2 with small natural horizontal emittance 6÷18 nm-rad at the electron energy 1.3 GeV and 2.5 GeV accordingly.

An achievement of the purposes means a radical improvement of an injection part of a SR complex. According to the Project, injection in Siberia - 2 will be made from a booster synchrotron (BS) with rather small natural emittance. The parameters of BS-1 and BS-2 are given in the Table 6.

Table 6: Calculated parameters of Booster Synchrotrons

Parameter	BS-1	BS-2
Injection energy, MeV	80-160	80-160
Extraction energy, GeV	2.5	2.5
Circumference, m	110.9	56.27
Cycling frequency, Hz	1	1
Emittance nm·rad	52.6	90.1
Momentum compaction	0.0107	0.032
Betatron tunes: Qx/Qy	6.83 / 4.57	5.186/2.352
Chromaticity: ξx/ξy	–14.12/–8.89	-8.85/-4.45
R.m.s. energy spread	9×10^{-4}	$1.95\text{x}10^{-3}$
Energy loss per turn, keV	622	622
Damping times: τ_x, τ_y, τ_s, ms	3.08, 2.97, 1.46	0.59/1.52/3.49
Beam current, mA	10	10
RF frequency, MHz	181.13	181.13
Harmonic number	67	34

BS will ramp the energy from 0.08 (0.16) GeV till 2.5 GeV with repetition rate of 1 Hz. BS will support the constant level of electron current in SIBERIA-2 and SR for the users (an "infinite beam life time"). Now there are two schemes (BS-1 and BS-2) of the BS location relative to Siberia-2 storage ring.

In Fig.8 the modernized complex is shown. Left: an external ring - Siberia-2, an internal ring - BS-1 is in the same tunnel, the linac with a projected magnetic mirror, the small ring - a SR source Siberia -1. Right: BS-2 is outside of tunnel of Siberia-2, Siberia-1 is dismounted.

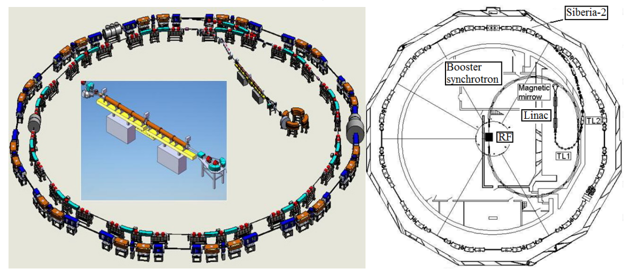

Figure 8: Two schemes of top-up energy injection.

Existing linear accelerator [8] will continue to work as injector for SIBERIA - 1 with electron energy 80 MeV. Besides, linac with a magnetic mirror will work as injector for BS-1 or BS-2 with doubled up to 160 MeV electron energy.

CONCLUSION

We hope that the scientific and technical decisions offered in the current modernization process will provide for a scientific attractiveness and competitiveness of SR source in Russian Research Center "Kurchatov Institute".

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