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STATUS OF THE KURCHATOV SYNCHROTRON RADIATION SOURCE

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Abstract

The Kurchatov synchrotron radiation source goes on to operate in the range of synchrotron radiation from VUV up to hard X-ray. An electron current achieved 200 mA at 2.5 GeV, up to 12 experimental stations may function simultaneously. An improvement of an injection process allowed to minimize injection time and to increase injection efficiency. A production of two new superconducting wigglers is now in progress in BINP (Novosibirsk). They will be installed on the main ring in next year. Great modernization of the whole facility is planned for 2020. The present status and future plans of the Kurchatov synchrotron radiation source is presented in the report.

INTRODUCTION

Kurchatov synchrotron radiation source (KSRS) consists of 80 MeV linac, 450 MeV small storage ring Siberia-1 and 2.5 GeV main storage ring Siberia-2 [1]. Siberia-1 serves as a booster ring for Siberia-2 while Siberia-2 supplies experimental stations by synchrotron radiation. Siberia-2 magnetic structure provides 98 nm horizontal emittance at 2.5 GeV. As a result of facility modernization Siberia-2 achieved electron current level of 200 mA. Now electron current is limited by RF system power. Further enhancement of the beam current is possible only after introducing of an additional RF generator. This is provided in Federal Program of the KSRS modernization in 2018 – 2020. The Federal Program also includes modernization of other facility systems such as vacuum, power supplies, water and air cooling, control system and so on. Two new 3 T superconducting wigglers will be installed on the main ring and several experimental stations will be constructed.

OPERATIONAL STATISTICS

As a rule Siberia-2 operates for SR users from the middle of September till the beginning of July. It works during 3 or 4 weeks in around-the-clock mode from Monday to Saturday. Then one week of preventive maintenance and machine tuning follows. Usually there is one beam storing per day (depends on beam lifetime). Storing of 200 mA takes approximately one hour, then energy ramping occurs for 3 minutes with 2 - 3 % current losses. During a day of operation beam current slowly decreases down to 40 – 50 mA so new storing is needed. Beam lifetime at 2.5 GeV depends on vacuum level and beam integral accumulated from the moment of last vacuum chamber violation.

Operational time and integral of the beam current of Siberia-2 have grown during last two years because of machine systems improvements (see Table 1). Three additional experimental stations and beamlines were installed. Number of simultaneously operating beamlines can reach 12. Shortage of the machine stuff prevents further operational time growing. Also facility cannot operate in summer time because of insufficient water and air cooling of the equipment.

Table 1: Statistics of Siberia-2 operation for last 4 years. Data for 2018 correspond to the beginning of September. Planned values for whole year are given in round brackets.

Parameter	2015	2016	2017	2018
Time for users, hours	2115	2755	2724	1680 (2700)
Beam integral, A·hours	115.5	178.8	200.3	127.6 (200)
Average number of stations in use	5.5	6.7	7.6	8.3
Average current, mA	54.6	64.9	73.5	76.0

BEAM CURRENT ENHANCING

A maximum value of Siberia-2 stored current depends on many parameters. Two main groups can be specified: stable work of the injection complex (that is storing rate in Siberia-1 and injection efficiency for Siberia-2) and beam stability in Siberia-2.

The Injection Complex Operation

In order to improve the operation of the injection complex following actions were taken:

- High voltage cables in klystron station “Olivin” feeding linac were replaced for modern ones. So risk of breakdowns at klystron’s anode was eliminated.
- New generator for “Olivin” station was put into operation. It not need multiplication of master frequency and operates at linac frequency of 2.8 GHz.
- In order to control short “Olivin” pulses modern digital oscillograph was put into operation. Thus the

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last microcomputer "Odrenok" in CAMAC standard produced in 1980's was decommissioned.

- New control system for pulse magnets was commissioned. It works under management of the program system for control and data acquisition CitectSCADA and has common archive with other systems of Siberia-2. Also an opportunity of nanosecond time periods measurements appeared. It allowed to faster tuning of Siberia-1 modes of operation.
- New power supply for injection septum magnet was put into operation. It uses block of 5 thyristors as an electronic switch instead of thyratron. It allowed to stabilize current through septum at the injection moment and to increase average injection efficiency. Stability of peak magnetic field in septum now is better than 10^{-3}.
- Geodetical alignment of main magnetic elements of Siberia-2 was made using laser tracker API Tracker LTS3-40. The very modern software for this procedure was acquired – Spatial Analyser in Ultimate version. Beam distortion of the closed orbit in the case of switched-off dipole correctors was used as a measure of the alignment quality. During this year mean-square orbit distortion at the beam position monitors was reduced by more than three times, down to 1.2 mm in horizontal plane and 0.85 mm in vertical plane. Also a correction of superconducting wiggler (SCW-1) position was made.

Now one injection cycle from Siberia-1 to Siberia-2 takes 30 seconds for 140 mA electron current (this value corresponds 10 mA Siberia-2 current because of a difference of the machines' circumferences). Siberia-2 injection efficiency achieved 60 - 63%, 10% more than one year ago. Storing of 180 mA in Siberia-2 now takes about 1 hour because of small beam lifetime at injection energy. The lifetime at injection (1 - 1.5 hours) is determined by Touchek effect. The lifetime at 2.5 GeV is defined by vacuum conditions and outgassing processes and reaches 16 hours at 100 mA and more than 50 hours in zero-current approximation.

Beam stability at Siberia-2

In order to increase beam stability modernization and tuning of preamplifiers in two RF generators were made. Now the stored current in Siberia-2 is limited by strong vertical oscillations which lead to beam losses. This effect can be partly suppressed by increasing a voltage of the RF cavities but it decreased the injection efficiency and a saturation of the stored current occurs.

The beam stability and maximal stored current depend also on time passed after vacuum chamber violation. Just after getting sufficient vacuum level after repair of the vacuum chamber the beam lifetime and maximal current are small. In the middle of 2017 opening of the Siberia-2 vacuum chamber was made in order to install equipment for new SR beamlines (vacuum valves and so on). Also a repair works in inflector section were produced to eliminate a heating of vacuum chamber wall by SR from previous bending magnet. As a result the heating of the inflector section now is 10 times less than earlier. After described works a long process of the outgassing of the vacuum chamber has followed (autumn of 2017).

ELECTRON BEAM DRIFT

Slow drift of the electron beam in vertical plane remains a great problem for SR users. It caused by machine fundament heating by aluminum bar supplying bending magnets. The heating of one side of the fundament leads to slope of the magnets and vertical orbit distortion. The aluminum bar has water cooling but water flow inside it is not sufficient to cool a surface of the bar. Also stabilization of water temperature is not adequate so the temperature rises at 3 - 4 degrees during 3 hours after energy ramping in Siberia-2. In order to minimize bar heating a number of parallel cooling branches was increased 3 times. As a result maximal orbit distortion decreased down to 0.2 mm from 0.5 mm. Further cooling growing needs more powerful pumps because of water pressure falling. At present a preparation for new pumps installing is underway and change of controlled valve in heat exchanger is planned. These actions will lead to stabilization of aluminum bar temperature in all modes of Siberia-2 operation (at injection and at working energy.

To compensate the drift of the vertical orbit a system of photon beam stabilization exists. For every radiation point a local orbit distortion is formed in order to keep a position of SR beam at special monitor point. The monitor contains luminophore stripe and TV camera with image analyzer. 4 - 6 micron mean-square stability of the photon beam is achieved by this system while SR beam size is about 5 mm. But it is not enough in several cases because the SR monitor is situated far from experimental stations and new beamlines often have complicated optical schemes.

The vertical orbit drift also leads to 10% increasing of the vertical beam size because of change in betatron coupling. Just after energy ramping transverse electron beam sizes are equal to 0.55 mm in horizontal plane and 0.10 mm in vertical one (mean-square values for radiation point in bending magnet). These values vary for different magnets, maximal sizes are given.

FEDERAL PROGRAM FOR KSRS MODERNIZATION

Federal Program assumes deep modernization of KSRS facility without changing general scheme of the accelerators' positions and functions. The program must be accomplished till the end of 2020. Its general features are as follows:

- Introducing of third RF generator and waveguide for Siberia-2. Modernization of preliminary amplification cascades in two old RF generators, power supply and control racks of whole RF system.

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- Modernization of vacuum system: new ion pumps with titanium evaporation modules, beam position monitors, valves, bells. Elimination of vacuum chamber heating by SR beam.
- Modernization of magnetic system power supplies.
- New generators for “Olivin” klystron station and pulse magnets.
- Modernization of water and air cooling systems of the facility equipment.
- Modernization of the machine control system in order to control new and upgraded equipment.
- New SR beamlines and experimental stations. Number of experimental stations will achieve 21 at Siberia-2.
- Two new superconducting wigglers SCW-2&3 with maximal field 3 T.

Siberia-2 general parameters (maximal beam current, beam lifetime, operational time, reliability and stability of operation) should be enhanced after program performing. Also modernization of facility building systems will take place that is ventilation, air conditioning, radiation situation control, etc. The stop for modernization will take whole 2020 year.

At present BINP (Novosibirsk) are producing two new SCWs and additional vacuum chambers for junction each SCW with Siberia-2 vacuum chamber [2]. They will be ready for magnetic measurements at the end of 2018. After that wigglers will be send to Kurchatov Institute and installed on Siberia-2 in the middle of 2019. Siberia-2 already has SCW-1 with maximal field up to 7.5 T. Unfortunately SCW cannot now operate at 7.5 T with electron current greater than several milliamps because of vacuum conditions. So the field level is limited by 4 T that allows having 100 mA current. Parameters of all wigglers are presented in Table 2.

Table 2: Wiggler’s Parameters

SCW parameters	SCW1	SCW2,3
Max field	7.5 (4) T	3 T
Field period	164 mm	48 mm
Number of poles	19+2	50+4
Undulator parameter	115 (61)	13.4
Emitted energy at 100 mA	35 (10) kW	4.2 kW
Vertical vacuum aperture	10 mm	10 mm

Wigglers are powerful sources of SR and strongly effects on beam dynamics in the machine. They cause vertical betatron tune shift, changes in betatron functions, horizontal emittance, power losses per turn and energy spread in the beam. In order to minimize wigglers’ influence SCW are installed in dispersion-free straight section. Vertical betatron function has to be small to decrease betatron tune shift (0.6 m in the middle of SCW straight section of Siberia-2). Siberia-2 parameters without wigglers and with different combinations of SCWs are presented in Table 3. Operation of all three wigglers requires introducing of third RF generator and at least 20% rising of accelerating voltage in order to keep former energy aperture and beam lifetime for reasonable beam current.

Table 3: Siberia-2 parameters without wigglers and with different combinations of wigglers. Relative values of the parameters are given in round brackets.

Siberia-2 parameters	-	SCW1 (4 T)	SCW2	SCW1+ 2SCW2
Horizontal emittance, nm·rad	98 (1)	85.5 (0.87)	92.3 (0.94)	76.1 (0.78)
Vertical betatron tune shift	0	0.0146	0.0049	0.0237
Energy loss per turn, keV	685 (1)	786 (1.147)	727 (1.061)	875 (1.277)
Relative energy spread, 10^{-3}	0.954 (1)	1.012 (1.062)	0.966 (1.014)	1.031 (1.081)

SCW undulator parameter is equal to 13.4, maximal angle of beam deviation equals 2.69 mrad. SR power density on the wiggler axe will be about 1 kW per mrad while total emitted power will achieved 4.2 kW for 100 mA electron current. So good and reliable cooling is needed for photon absorbers and other details in SCW beamline during wiggler operation.

CONCLUSION

KSRS accelerator facility continues effective work for SR users. During last two years maximum values of beam current and operation time are achieved. The facility modernization must lead to further growth of its parameters.

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