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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 achieves 120 mA at 2.5 GeV, up to 12 experimental stations may function simultaneously. Improvement of the facility according Federal Program of KSRS modernization is in progress. Two 3 Tesla superconducting wigglers have been installed at main ring at 2019. They were tested with small electron beam current at 2020-2021. Wigglers' influence on beam parameters is much closed to calculated value. Vacuum system has been upgraded at 2020. In 2021 control system will be completely modified. Manufacturing of third 181 MHz RF generator, new preliminary amplification cascades and new waveguides for all three generators continues in Budker Institute (Novosibirsk). Preparation of great modernization of the whole facility according Federal Program for science infrastructure development has been started.

INTRODUCTION

A 2.5 GeV electron storage ring Siberia-2 is a main source of synchrotron radiation (SR) at Kurchatov Synchrotron Radiation Source (KSRS) facility. A magnetic structure of Siberia-2 provides 98 nm·rad horizontal emittance of an electron beam, electron current achieves 150 mA. At present Federal KSRS modernization program (below – Program 1) is in progress, it was prolonged till 2022. Within the scope of Program 1 a third 181 MHz RF generator was manufactured in addition to two existing generators of Siberia-2. Besides 2 new identical superconducting wigglers (SCW) with 3 Tesla maximal magnetic field were put in operation during 2019 – 2021. They were tested with small electron beam. In 2019 – 2020 a modernization of vacuum system was completed, now control system modernization is close to completion.

At 2020 a preparing to deep KSRS modernization has been started according to Federal Program for Scientific Infrastructure Development (below – Program 2). As a result of Program 2 all KSRS accelerators must be replaced to new ones. New main 2.5 GeV KSRS ring should have horizontal emittance less than 3 nm·rad and top-up injection from booster synchrotron. Only RF system, SCWs and SR beamlines will be retained from old KSRS equipment. Because of Program 2 appearance some items were cancelled from Program1.

OPERATIONAL STATISTICS

As a rule Siberia-2 operates for SR users during 9 months per year. It functions 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. Storing of 150 mA takes approximately one hour, then energy ramping occurs for 3 minutes with 2 - 3 % loss of current. Then 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.

As a result of KSRS development a stable facility operation was achieved during last several years (see Table 1, values for 2021 correspond to first half of the year.). But prominent decrease of these values occurred in 2020. Mostly it was caused by coronavirus pandemic which lead to KSRS shutdown at April-May and December. A long summer break for vacuum system modernization was one more reason. Finally initial plan for duration of users' work was completed only by 55% (in comparison with 100 – 110% during previous 4 years). Activity of SR users also was lower for the same reasons. But in 2021 all values became close to normal ones.

Table 1: Statistics of Siberia-2 Operation for last 4 Years

Parameter	2018	2019	2020	2021
Time for users, hours	3035	2728	1202	1706
Beam current integral, A·hours	227.1	200.1	88.8	105.0
Average number of stations in use	7.4	7.4	5.6	10.6
Average current, mA	74.8	73.4	73.9	61.5

FEDERAL KSRS MODERNIZATION PROGRAM (PROGRAM 1)

KSRS modernization according Program 1 should not change overall scheme of the facility, all magnetic elements are the same. The facility still consists of two storage rings (Siberia-1 and Siberia-2), linac and two

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transport lines. Realization of Program 1 has been longed till the end of 2022. Some points of Program 1 are described below.

RF System

RF system modernization includes: manufacturing of third RF generators for Siberia-2 and modernization of preliminary amplification cascades of two existing RF generators; manufacturing of low and high voltage supply racks; racks with control equipment; new waveguides. All three RF generators will be identical. All new parts of RF system were produced in Budker Institute of Nuclear Physics (BINP, Novosibirsk). They will be sent to Kurchatov Institute at the end of 2021. An assembling of RF equipment is included to Program 2 as well as production of supplying and cooling service lines and electricity supply system.

Vacuum System

KSRS vacuum system has got a lot of new equipment. 15 new pneumatic-drive vacuum valves were installed at Siberia-2, one as minimum for every straight section, two for injection section and for sections with superconducting wigglers. Now there is a possibility to produce repair of the chamber only at separate regions. Before it only RF cavities could be isolated. Four valves were installed at beam transport lines. Siberia-2 has got 21 new BPMs in addition to 24 old ones. Five new BPMs mounted on transport line from Siberia-1 to Siberia-2 instead of four BPMs with old design. Most of ion pumps were replaced at Siberia-2, titanium evaporation units were updated in all ion pumps. Also modernization includes new vacuum meters, bells, mass-spectrometers, new aluminum vacuum chambers for Siberia-2 straight sections.

Two new superconducting wigglers SCW2 and SCW3 (2 or 3 means a number of Siberia-2 superperiod) were installed in 2019 summer. Additional photon absorber was added to SCW straight section in order to protect wiggler vacuum chamber from synchrotron radiation from previous bending magnet. At the same time part of vacuum chambers near old wiggler SCW1 was replaced in order to increase vertical aperture for SR beam from SCW1. All other works were made in 2020. An outgassing of Siberia-2 vacuum chamber was done after all; electron current value and beam lifetime sufficient for SR users were achieved at November of 2020.

New Superconducting wigglers

BINP produced for KSRS two identical superconducting wigglers in 2019 [1]. Maximal magnetic field of SCW equals 3 Tesla with 48 mm period. Wiggler's magnet consists of 54 poles: 50 central poles with nominal field 3 T and 4 side poles. SCWs were transported to KSRS and tested outside Siberia-2 shielding. Nominal field was achieved successfully. After that wigglers were installed on Siberia-2. View on SCW3 is presented on Fig. 1. Simultaneously special technological area was constructed for installing of wiggler's equipment (power supplies, compressors, water cooling systems and computers). The area is situated at the level of the shielding roof inside the ring. Tracks for helium flexlines, feeding and control cables, from the technological area to wigglers were also mounted.

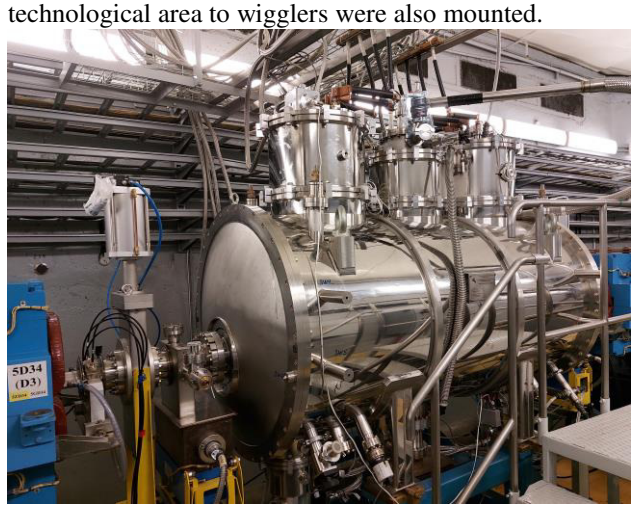

Figure 1: New 3 Tesla wiggler on Siberia-2 (SCW3).

At the beginning of 2020 SCW3 was tested with 3 T with electron beam, two wigglers were tested simultaneously in 2021 after assembling of all supplying equipment. Electron current didn't exceed 4 mA. Larger current is not possible yet, because there are not adequate photon absorbers in SCW's beamlines. Absorbers inside Siberia-2 vacuum chamber are not dedicated for great SR power density from wigglers. The power density can achieve 1000 W/mrad in the center of SR beam for 100 mA electron current at 2.5 GeV. Total emitted SR power will be 4.2 kW in this case.

Wigglers 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 with small vertical betatron function.

Figure 2 presents dependence of betatron tune shifts on magnetic field in SCWs during its separate operation. Then they are work together a total betatron tune shift is coincide with sum of individual values with good accuracy. A dependence of vertical betatron tune shift on SCW field is close to quadratic one. It corresponds to theory if vertical betatron function in the center of SCW equals 0.75 m (SCW2) and 0.8 m (SCW3).

The wigglers cause closed orbit distortion at all machine azimuths. Maximal horizontal orbit distortion (60 microns at 3 T in both SCWs) is relatively small in comparison with beam size. Besides it can be decreased by changing proportions of supplying currents. Vertical orbit distortion achieved 450 microns at 3 T in both wigglers. It means discrepancy between physical and magnetic axes of the wigglers. Vertical shift of magnetic axe is equal to 2 – 2.5 mm. It is rather big value in comparison with vertical aperture of SCW's vacuum chamber (10 mm). However such orbit distortion can be

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corrected by dipole correctors of the ring. Besides correction of the wiggler's vertical position may be done.

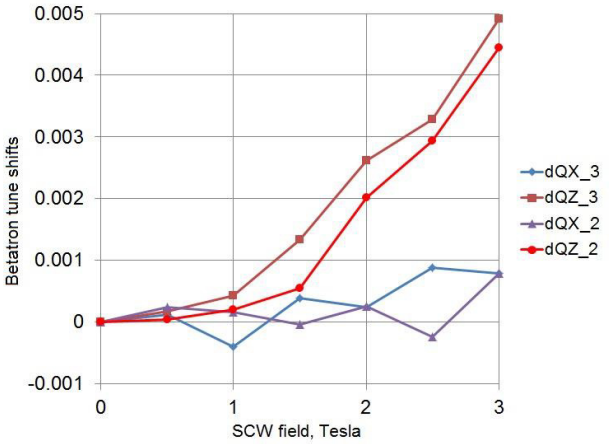

Figure 2: Dependence of betatron tune shifts dQX (horizontal plane) and dQZ (vertical plane) on wiggler's field during separate operation of SCW2 and SCW3.

KSRS control System

KSRS control system provides management of more than 2000 executive channels and 5000 measuring ones. At present control system includes two great parts: one part under control of CitectSCADA server (most of the equipment), second under control of PC CANServer (magnets and RF generator of Siberia-2 injection complex, pulse synchronization). Second part so far uses old CAMAC modules. Closed orbit in Siberia-2 and beam position in transport line are also measured independently. CANbus is preferably used to connect hardware. Main ideas of the modernization are to organize unified control system under management of modern version of CitectSCADA, to proceed to Ethernet links and optic cables for pulse synchronization. Modern control system has to ensure stable and reliable operation of KSRS, to increase useful beam parameters for SR users. It should contain new subsystems and hardware listed below:

- For vacuum system: 65 new modules BUP-M for ion pumps control, 12 new racks in Siberia-2 hall for Ti evaporation units and vacuum valves control.
- For RF system: new modules for all RF generators control, measurement of RF power in waveguides and temperature of RF cavities.
- New pulse synchronization system using optic cables, removal of CAMAC modules.
- For magnet system: 60 new modules BUK-M for high- and low-current power supplies control.
- New thermal stabilizing scheme for linac structure.
- Additional modules Libera Brilliance for Siberia-2 closed orbit measurement, 5 new modules Libera Spark for trajectory measurements in electron transport line. 7 new racks for Libera modules in Siberia-2 hall. All these modules are manufactured by International Technology (Slovenia).
- New server hardware and terminal devices.
- System for integrating pulse magnets' supply currents.

Also new control system has to include KSRS subsystems that were modernized earlier:

- Control of movable SR absorbers.
- Themperature control system.
- System of unified time.
- Pulse magnets' power supplies.
- Wigglers' control systems.
- Electron beam current measurement.

New control system software should provide reliable management of all KSRS subsystems, execution of necessary operation algorithms, collecting, transporting, representation, storing of all data, and notification about emergency situations.

FEDERAL PROGRAM FOR SCIENTIFIC INFRASTRUCTURE DEVELOPMENT (PROGRAM 2)

The Program 2 has to be finished in 2027. According to this Program all KSRS accelerators must be dismounted and be replaced with new ones. Instead of Siberia-2 with 98 nm·rad horizontal emittance new SR source should appear with emittance less than 3 nm·rad. A booster synchrotron will be used as injector to new ring. Injection is planned on working energy 2.5 GeV with 1 second cycle. New linear accelerator with energy 200 MeV will serve as injector for the booster synchrotron. More details of Program 2 are presented in [2]. Part of modern KSRS equipment will stay in new facility: RF system (after modernization according Program 1), superconducting wigglers, SR beamlines and part of control system modules. After Program 2 appearance several items of modernization were moved from Program 1 to Program 2. Among them mounting of new RF generator and waveguides, water cooling system, electric power supply system should be mentioned. Because of Program 2 appearance some items of Program 1 was eliminated. For example, modernization of high-current power supplies was cancelled.

CONCLUSION

KSRS is keeping on working effectively for SR users. Present modernization has to provide improvement of facility parameters. As a result of global modernization according to Federal Program of Scientific Infrastructure Development new bright source of synchrotron radiation will be created.

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