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NEW SUPERCONDUCTING WIGGLERS FOR KSRS

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Abstract

Presently a program of incorporation of two new superconducting wigglers into main ring of Kurchatov synchrotron radiation source is implemented in NRC Kurchatov Institute. The wigglers are intended for new experimental stations "Belok-2" (biology studies) and "VEU" (exploration of materials in extreme conditions). The wigglers are designed for maximal magnetic field 3 T with 48 mm period and contain 50 pairs of poles with maximum field. Technical details of wigglers' construction are presented in the report along with a description of testing and mounting procedures. An influence of the wigglers on beam dynamics is described.

INTRODUCTION

At present BINP (Novosibirsk) are producing two superconducting wigglers (SCW) with maximal magnetic field 3 T for Kurchatov Synchrotron Radiation Source (KSRS) [1]. This work is included in Federal Program for KSRS modernization. Magnetic measurements of the wigglers are planned to fulfil at the end of 2018. In the middle of next year they will be installed on main storage ring of KSRS.

BINP has wide experience in construction and producing of such wigglers [2] with different field levels and field periods. They are installed and put into operation on many SR facilities. For every machine follows parameters must be taken into account:

- Required synchrotron energy range.
- Dimensions of a straight section for SCW.
- Parameters of an electron beam at SCW azimuth, operational modes of given machine.
- Vacuum condition and vacuum chamber construction.
- Influence and geometry of SR from previous bending magnet.
- Convenient installation and maintenance of SCW.

SCW MAGNETIC SYSTEM

The magnetic system of SCW is optimized to get maximal flux of SR in spectral range between 10 and 35 keV. Wiggler's magnet consists of 54 poles: 50 central poles with nominal field 3 T and 4 side poles. Field period is equal to 48 mm; the field is oriented in vertical direction and changes by sinusoidal law. Magnet gap between top and bottom poles is 14 mm. Poles with magnetic field ¼ and ¾ from nominal value are situated on both side of the SCW. Its geometry and field distribution provide coincidence of wiggler and machine straight section axes. Zero values of first and second field integrals along the wiggler axe are maintained by regulation of currents in coils of the side poles. Scheme of the wiggler prototype with 4 central poles and beam trajectory inside the wiggler are presented on Fig.1.

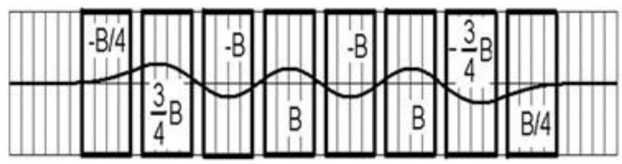

Figure 1: An electron beam trajectory in horizontal plane inside the wiggler prototype. B is nominal vertical magnetic field.

Every pole consists of pair of iron yokes of racetrack type with superconducting coils on them. The yokes are situated symmetrically (above and below) with respect to vacuum chamber. A conductor of the coil is NbTi alloy wire in copper matrix. The wire is coated by varnish isolation layer. The coils are wide enough to provide homogeneity of the magnetic field in horizontal direction not less than 10^{-3} inside ±6 mm.

The coils of central poles have two sections with different currents inside them (4 layers of the wire in both section, 62 turns per section). The coils of side poles have only one section with 2 or 8 wire layers. Outer section of the central pole is fed by greater current than inner one because it is situated in lower magnetic field.

VACUUM CHAMBER

Vacuum chamber aperture is equal to 10 mm in vertical plane and 60 mm in horizontal plane. Minimal thickness of the chamber is 0.5 mm. The chamber has elliptical form in central region of the wiggler and widens to the ends of the wiggler in order to provide smooth transition to machine vacuum chamber. The chamber was produced from aluminum alloy 6063 by extrusion procedure.

The vacuum chamber has temperature at the range between 10 K and 20 K and is thermally isolated from magnetic system of the wiggler. Stainless steel flanges are used at both sides of the chamber to connect it with machine vacuum chamber. Maximal energy inflow from synchrotron radiation and electron beam image currents is estimated to be less than 10 Watt for normal operation of cryosystem.

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POWER SUPPLIES

The wiggler has 4 power supplies to provide acceptable current in superconducting coils. The power supplies has maximal current 300 A and maximal voltage not less than 10 V. Four supplies instead of two are used for minimizing current through cryostat current lead and for decreasing by half heat dissipation inside non-superconducting solder contacts. The power supplies have stability ΔI/I not more than $2\cdot10^{-5}$ and 16 bit resolution for current control. This power supply was specially constructed for stable operation with low inductive load. Maximal time for growing and decreasing of the field between 0 T and 3 T does not succeed 5 minutes. Relationship among the currents in power supplies for any field level is determined after magnetic measurement under condition of zero field integrals. Inner sections of the central poles are fed from one pair of the power supplies while outer section is fed from all 4 supplies. The current is introduced to cryostat through special HTSC rods. External view of the power supply is shown on Fig.2.

Figure 2: External view of the wiggler power supply.

CRYOSTAT AND SYSTEM FOR LOW TEMPERATURE SUPPORTING

Wiggler cryogenic system is constructed as a vacuum vessel where low temperatures of the magnetic system and thermal shields are supported by thermal contacts with 4 two-stage Sumitomo cryocoolers. The magnetic system is protected from thermal radiation heating by two copper thermal shields with temperatures 20 K and 60 K. The shields are connected with different cold-heads of the cryocoolers. One pair of cryocoolers has 20 K/60 K cold-heads, while other pair has 4.2 K/60 K cold-heads. Superconducting magnet is situated in isolation vacuum, its temperature 4.2 K is provided by special system of pipes with liquid He (so called indirect cooling). Liquid helium is contained in a separate vessel and is cooled by cryocoolers' cold-heads. The cryogenic system minimizes thermal load on superconducting coils and supporting details in normal operation mode. The vacuum chamber is connected with 20 K cold-heads of the cryocoolers.

An ion pump provides residual gas pressure $1\cdot10^{-6}$ mbar inside cryostat in working conditions.

The cryocoolers are connected with their compressors by 30 m flexlines. The compressors provide operation of the cryocoolers, they are situated outside machine biological shielding. They consume up to 10 kW of electrical power each and have water cooling.

A body of the cryostat has special geodetic marks in order to simplify its alignment relative to machine elements.

A scheme of the cryostat is shown on Fig.3.

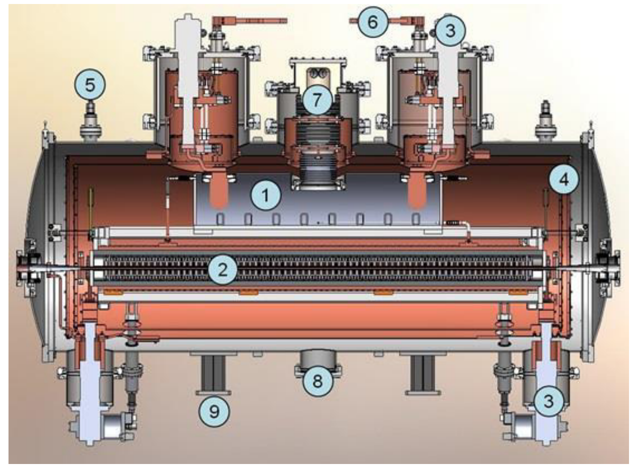

Figure 3: Wiggler cryostat scheme. 1 – vessel with liquid helium and pipes for cooling of the magnetic system, 2 – magnetic system with vacuum chamber inside, 3 – cryocoolers (2 on top and 2 below), 4 – copper thermal shields, 5 – elements for suspension of the magnetic system inside the cryostat, 6 – current leads, 7 – central opening for liquid helium filling, 8 – ion pump flange, 9 – support detail.

MONITORS AND CONTROL SYSTEM

Each wiggler has separate control system. There are set of different monitors inside the cryostat: monitors of temperature, liquid helium level, He vapor pressure, vacuum level, quench detector. Data from monitors are collected in special control unit. The unit also contains processor controlling power supplies and compressors of the cryocoolers. A computer program for wiggler's system control operates in personal computer. The program will be connected with facility control system according specially designed protocol.

VACUUM CHAMBERS OF THE KSRS MAIN RING AROUND THE WIGGLER

In order to protect wiggler vacuum chamber from synchrotron radiation from previous bending magnet special copper photon absorber is provided before the wiggler. Distance between the absorber and straight section axe is equal to 20 mm in horizontal plane. The absorber is placed inside special unit with ion pump. There are also vacuum valve, beam position monitor and bell before the wiggler. After the wiggler ion pump, beam position monitor and bell are situated. Ion pumps and vacuum valve have separate regulated supports. All equipment will be installed simultaneously with wiggler.

MAGNETIC MEASUREMENTS IN BINP

Wiggler prototype with 6 central and 4 side poles was assembled and tested in BINP in July 2017 in submersible

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cryostat. After some quenches and coil training field level of 3.8 T was achieved. This level is far above designed value. Maximal field inside the cryostat with indirect cooling will be slightly less but still more than 3 T. The magnetic measurements have demonstrated good accordance of the designed field parameters to calculated ones. View of one half of the prototype magnet is shown on Fig.4.

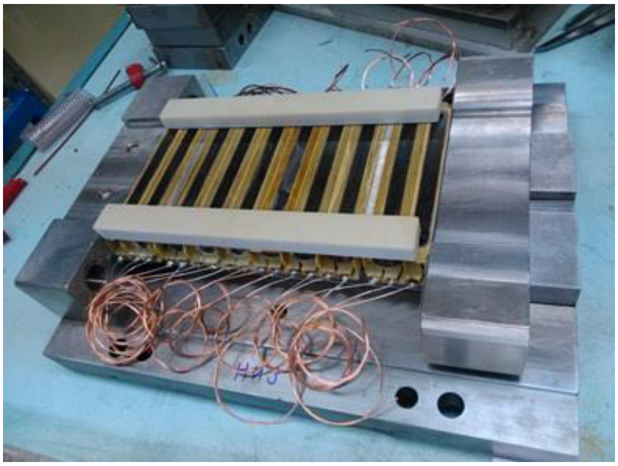

Figure 4: External view of the SCW prototype magnet.

By this moment all poles for two SCWs and magnet yokes had been manufactured. Presently a producing of cryostats is under way. Superconducting coils are shown in Fig.5 before installing on magnet yoke. Magnetic measurements of fully assembled SCWs will take place in the end of 2018.

Figure 5: Superconducting coils for 3 T SCW.

PLANS FOR SCW INSTALLING ON THE RING

The wigglers will be transported to Kurchatov Institute at the beginning of 2019. They will be assembled outside biological shielding of the KSRS main ring. Then magnetic measurements will be done. SCWs will be installed on the main ring in the first half of 2019. Special technological area are planned to be constructed for installing of wiggler's equipment (power supplies, compressors, water cooling systems, computers). The area will be situated at the level of the shielding roof inside the ring.

SCW'S INFLUENCE ON BEAM DYNAMICS

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 KSRS main ring). Machine parameters without wigglers and with different combinations of SCWs are presented in Table 1. Operation of two wigglers requires at least 10% rising of accelerating voltage in order to keep former energy aperture and beam lifetime for reasonable beam current.

Table 1: KSRS main ring parameters without wigglers and with different combinations of wigglers. Relative values of the parameters are given in round brackets.

Machine parameters	-	1 SCW	2 SCW
Horizontal emittance, nm·rad	98 (1)	85.5 (0.87)	92.3 (0.94)
Vertical betatron tune shift	0	0.0146	0.0049
Energy loss per turn, keV	685 (1)	786 (1.147)	727 (1.061)
Relative energy spread, 10^{-3}	0.954 (1)	1.012 (1.062)	0.966 (1.014)

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 facility will get new experimental opportunities after SCWs' installing and putting into operation.

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