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A MULTIPOLE SUPERCONDUCTING WIGGLER FOR CANADIAN LIGHT SOURCE

E. A. Bekhtenev, S. V. Khruschev, E. A. Kuper, V. H. Lev, N. A. Mezentsev, E. G. Miginsky, V. V. Repkov, V. A. Shkaruba, V. M. Syrovatin, V. M. Tsukanov

Budker Institute of Nuclear Physics, Novosibirsk, Russia

A contract for multipole superconducting wiggler design and fabrication between the University of Saskatchewan (Canada) and Budker Institute of Nuclear Physics (BINP) was signed in October 2003. The wiggler with the photons energy range from 4 to 40 keV, the maximum field 1.9 T and the period length as small as possible was required for the micro-XAFS beamline. In 2004 the 2 T 63-pole superconducting wiggler with the average period length 34 mm was fabricated at BINP. To eliminate the undulator type spectrum the periodicity of the wiggler was broken. A new approach to the cryostat design enabled the long time (up to 6 months) machine operation without liquid helium refilling (LHe consumption < 0.03 l/h). In January 2005 after successful tests the wiggler was installed on the Canadian Light Source (CLS) storage ring with the energy 2.9 GeV. The main parameters of the magnet and the cryogenic systems as well as magnet measurements data, cryogenic system test data and experimental results during machine operation on the CLS storage ring are presented.

В октябре 2003 г. между Университетом Саскачевана (Канада) и ИЯФ им. Г. И. Будкера СО РАН был заключен контракт на изготовление сверхпроводящего вигглера для станции микро-XAFS в Центре синхротронного излучения CLS. Вигглер должен был покрывать энергетическую область фотонов 4–40 кэВ при максимальном поле 1,9 Тл и минимально возможном периоде. В 2004 г. 63-полюсный вигглер с рабочим полем 2 Тл при среднем периоде 34 мм был сконструирован и изготовлен в ИЯФ. Для того чтобы избежать изрезанности спектра, периодичность вигглера была нарушена. Новый подход к конструкции криостата обеспечил возможность длительной (более 6 месяцев) работы устройства без заправки жидким гелием (расход гелия менее 0,03 литра в час). В январе 2005 г. после успешных испытаний он был установлен на накопительном кольце CLS с энергией 2,9 ГэВ. В настоящее время ведутся эксперименты по исследованию СИ. В работе дается описание магнитной и криогенной систем сверхпроводящего вигглера, приводятся данные по магнитным измерениям, испытанию криогенной системы и результаты работы вигглера с пучком электронов на накопителе CLS.

INTRODUCTION

A superconducting 63-pole wiggler (SCW) for CLS has been designed and fabricated at Budker INP (Novosibirsk, Russia) according to technical requirements of the contract signed between the University of Saskatchewan (Canada) and Budker INP. In 2005 the wiggler was successfully tested at CLS site and installed on the storage ring (see Fig. 1). The wiggler has been developed as a powerful synchrotron radiation source in photon energy range 4–40 keV for the micro-XAFS beamline.

The SCW represents a magnetic system consisting of 63 bending magnets with transverse magnetic field [4]. Field amplitude in the median plane is 2 T. Superconducting windings are

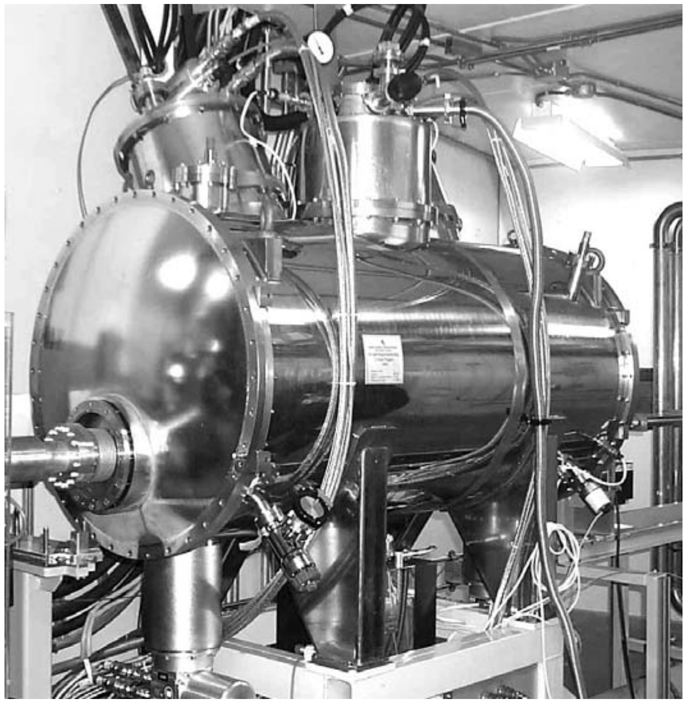


Fig. 1. Photo of 2 T 63-pole superconducting wiggler for Canadian Light Source

made from Cu/Nb–Ti wire. The magnet is placed into the liquid helium vessel at temperature 4.2 K. The SCW system consists of:

- Magnet system;
- Cryogenic system with insulating vacuum;
- Power supplies and quench protection system.

Control system designed for SCW system control and monitoring includes temperature probes, LHe level meter, gas helium pressure meter and interlock system. It allows one to obtain system state information and to provide reliable device protection.

1. SPECTRAL CHARACTERISTICS OF WIGGLER RADIATION

Multipole wigglers represent sign-alternating magnetic structure with many poles with high magnetic field [1]. Electron beam passing through multipole wiggler concentrates SR from all poles into the same horizontal angle and increases photon flux. In an ideal case, for infinitely long periodic wiggler and for zero energy spread in electron beam the spectrum of radiation is a line spectrum with peak energy values defined by the expression

$$\varepsilon_n = \frac{2\gamma^2 \hbar n}{\lambda_0 (1 + K^2/2)}, \tag{1}$$

where n is the harmonic number; γ is the relativistic factor; λ_0 is the undulator period; B_0 is the magnetic field amplitude in median plane; K is the undulator parameter defined by the relation

$$K = 0.934\lambda_0[\mathrm{sm}]B[\mathrm{T}]. \tag{2}$$

The maximum of radiation intensity from the wiggler corresponds to harmonic number

$$N_{\max} \approx 3/8K^3. \tag{3}$$

For the CLS wiggler the above parameters are: $K \sim 6.3$, $N_{\max} \sim 95$ and photon energy of the basic harmonic is equal to 0.11 keV. In real situation the spectrum of radiation is continuous due to final number of the wiggler periods, existence of energy and angular spread in electron beam.

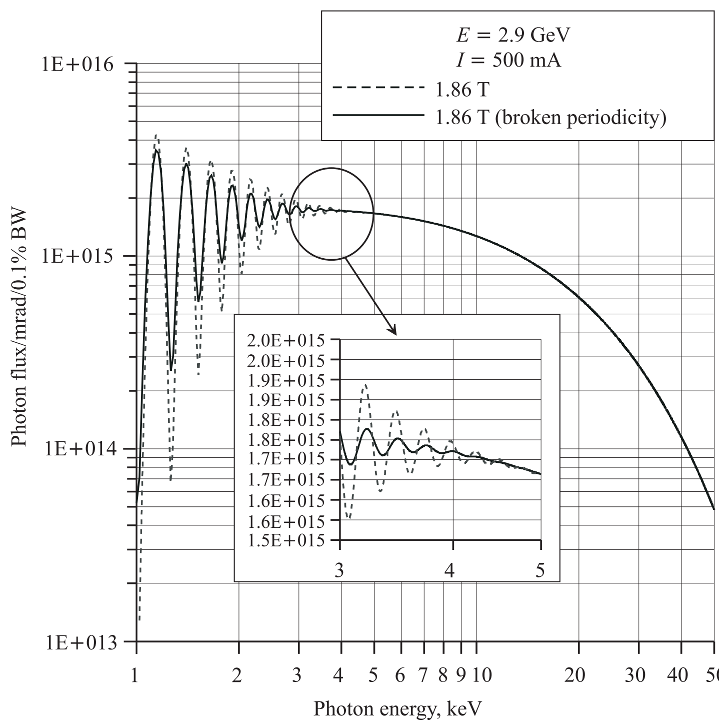


Fig. 2. Spectrum of radiation from CLS SC wiggler

The presented wiggler has a rather complicated spectral structure (see Fig. 2) with transition from the undulator radiation spectra to the spectra of sign-alternating bending magnets array (wiggler) depending on the energy of photons. XAFS experiments require smoothness of spectrum in range 4–40 keV. Effects of electron beam energy spread and final number of wiggler poles are not enough for spectrum smoothness in photon energy area 4–10 keV. To provide the required spectrum smoothness in low energy range it was decided to bring a casual disorder in the wiggler periodicity.

2. WIGGLER MAGNET SYSTEM

Superconducting NbTi wire with lacquer insulation was used to produce the wiggler coils. The parameters of the superconducting wire can be found in Table 1.

Table 1. **Superconducting wire parameters**

Wire diameter with/without insulation, mm	0.91/0.85
Ratio of NbTi : Cu	1.4
Number of filaments	312
Critical current at 7 T, A	510–550
Number of filaments in wire	312

The magnetic field on the wiggler median plane is created by 122 central and 4 side coils wound over the ARMCO-iron cores. The shape of the central pole is a racetrack type with dimensions of 88×16.6 mm and a height of 23.85 mm. Central coils are energized by two independent power supplies with maximum current 400 A each, where currents are summarized. Additional 4 side coils are energized by one power supply giving a possibility to adjust first field integral to zero [2, 3].

The ARMCO-iron yoke is used to return the magnetic flux and to support the coils. The length of the magnet yoke is 1120 mm. The yoke includes two parts which are placed symmetrically above and below the median plane of the wiggler. The upper and the lower wiggler parts are supported by the nonmagnetic stainless steel slab located symmetrically between the halves. The additional iron plates between the upper and the lower halves are

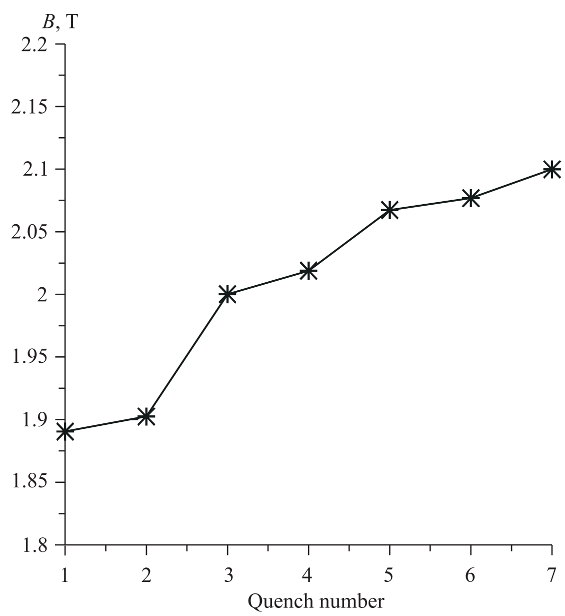


Fig. 3. Quench history of the wiggler magnet inside a bath cryostat

used to close the stray magnetic flux. The dimension of the vertical magnetic gap between the coils is equal to 13.5 mm.

Training of the wiggler coils by quenches was carried out during wiggler test. Magnetic field of 2.2 T in the median plane was achieved after 7 quenches. Quench history is shown in Fig. 3.

3. WIGGLER CRYOGENIC SYSTEM

The cryogenic system consists of external housing, 60 K shield, 20 K shield, liquid helium vessel, throat, vacuum chamber with a copper liner, upper flange, filling tube, two Leybold 4.2GM One Watt System coolers, two shield Leybold Coolpack 10MD coolers and an ion pump. The SCW magnet is placed into a special liquid helium vessel having a working volume 330 l of liquid helium.

Two shield screens to reduce the irradiation heat flux from outside surround the inner liquid helium vessel. The temperature on the outside shield screen is about 50 K, on the inner one it is 20 K. There is vacuum insulation between the helium vessel and the 20 K screen as well as between the both screens and 50 K shield and an external warm stainless steel vessel to reduce the heat flux.

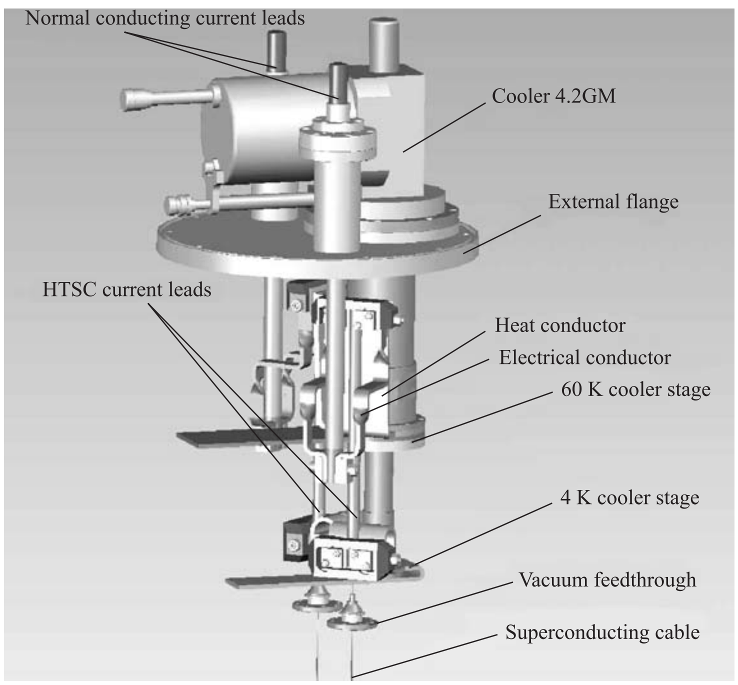


Fig. 4. Assembling of current leads with cooler

Two pairs of current leads are used for feeding the magnet with current 400 A. These current leads are the main source of heat in-leak into liquid helium vessel due to both heat conductivity and joule heat. Each current lead consists of two parts: normal conducting brass cylinder and high-temperature superconducting ceramics. One pair of current leads assembled into one block together with the 2nd stage cooler 4.2GM (see Fig. 4) which is placed in the insulating vacuum of the cryostat. The junctions of normally conducting and superconducting parts of current leads are supported at temperature 50–65 K by the first stage of coolers. The lower part of a superconducting part of the current lead is connected with superconducting Nb–Ti cable and supported at temperature below 4.2 K with the help of the second stage of the coolers. This design allows one to obtain average liquid helium consumption less than 0.03 l/h and provides liquid helium refilling about one time per year at normal operation conditions.

The wiggler vacuum chamber for electron beam is a part of liquid helium vessel and has a temperature of 4.2 K. To prevent liquid helium consumption due to electron beam heating a copper liner is inserted into the vacuum chamber.

The insulating vacuum system purposes to reduce the heat flux from the warm external walls of the cryostat to the inner helium vessel through a residual gas. The common insulating vacuum occupies a volume between the internal part of the SCW housing and the external part of the liquid helium tank joined together. A required vacuum for cryostat operation is equal to 10^{-5}–10^{-7} Torr.

4. POWER SUPPLIES AND QUENCH PROTECTION SYSTEM

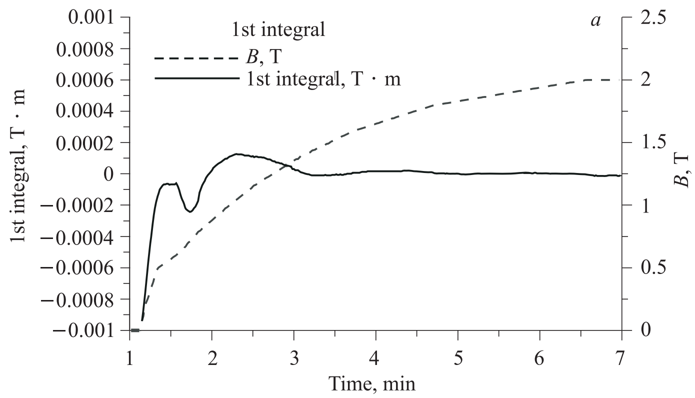
DANFYSIK Magnet Power Supplies 883 (400 A/10 V, ± 25 ppm long term stability, RS232 interface) are used for magnet energizing. The power supply units are used to feed the central and side coils. Superconducting coils of the wiggler are protected from damaging during quench by shunts with resistance of 0.1 Ω and cold diodes.

5. TEST RESULTS

SCW system tests included procedure of cooling down and warming up, demonstration of field stability at maximum field, fine tuning of currents in the magnet for zero field using stretched wire method (see Fig. 5), Hall probe measurements for field mapping, LHe consumption tests, etc. The main wiggler parameters are presented in Table 2.

The temperature behavior of main temperature probes, measuring temperatures at various points of the system versus wiggler magnetic field is shown in Fig. 6. The main effect of temperature increase is seen at the top ends of superconducting high-temperature current leads at maximal currents in the magnet. The temperature growth is within the allowed limits and does not influence the liquid helium consumption in the system. During the wiggler commissioning at field 2 T the zero value of liquid helium consumption was found.

Magnetic measurements with the use of two Hall probes as perpendicular array were conducted at the following field levels: $B = 0$ (after slow ramping down), $B = 1$ T, $B = 1.6$ T, $B = 1.8$ T, $B = 2$ T, $B = 0$ (after quench) at $x = 0$, $z = 0$. For field level $B = 2$ T the magnetic measurements were done for $x = 0$, ± 5, ± 10, ± 15 mm. The results of these measurements are shown in Fig. 7.



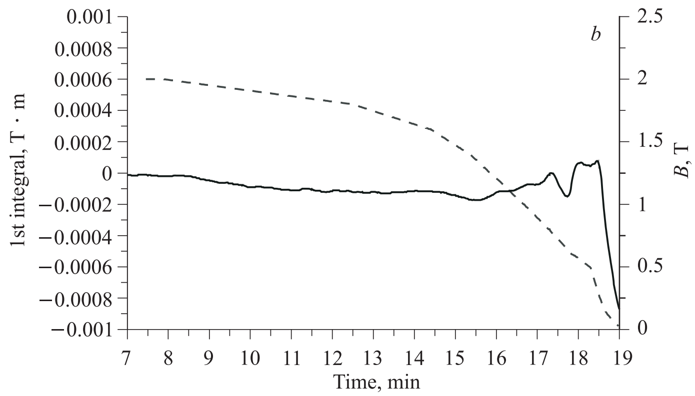


Fig. 5. Dynamics of wiggler first field integral during field ramping

Table 2. **Main SCW system parameters**

Parameters	Required value	Real value
Period length, mm	~ 33	34
Number of pole	63	63
K value	~ 6	6.5
Vacuum chamber (vertical), mm	9.5	9.5
Vacuum chamber (horizontal), mm	50	50
Pole gap		13.5
Temperature of the vacuum chamber, K		15–20
Shield screens temperature, K		20, 50
Electrical current in the coils, A		730
Time between LHe refilling, months	3–6	6–12
LHe volume of the cryostat, l		330
Working magnetic field, T	1.86	2
Achieved magnetic field, T		2.2
Ramping time 0–2 T, min	5	5

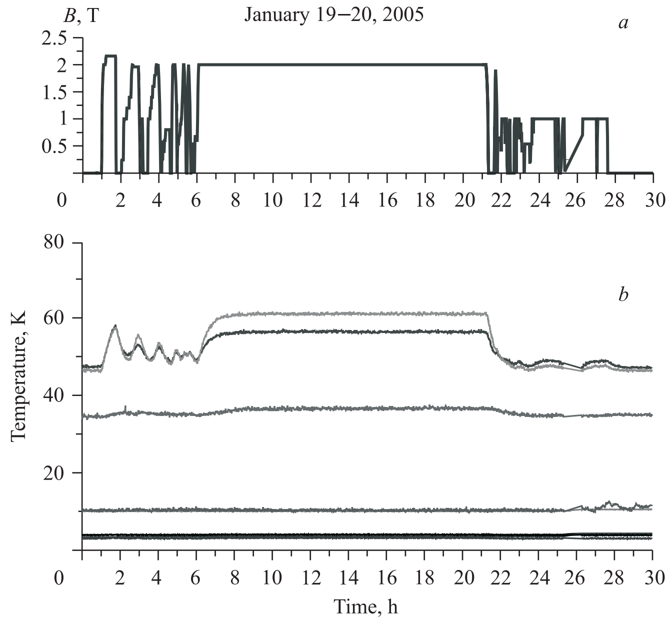


Fig. 6. Main temperature probes values versus time at different field levels of the wiggler

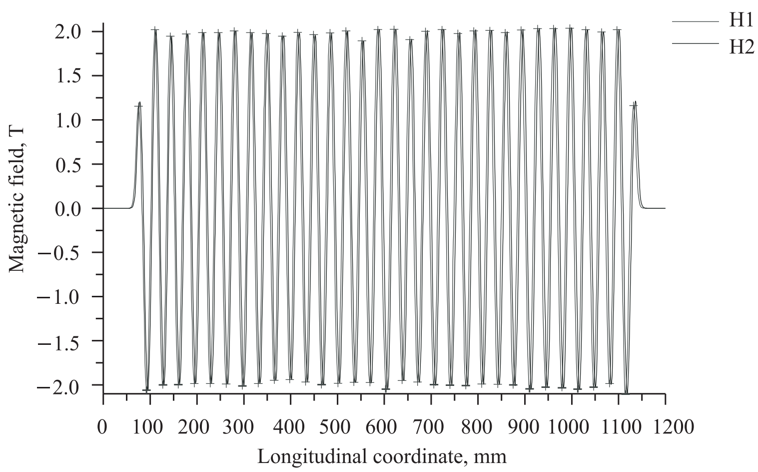


Fig. 7. Hall probe measurements

CONCLUSIONS

Planar type superconducting 63-pole wiggler with short period 34 mm was successfully tested and installed on the CLS storage ring. The maximum magnetic field 2.2 T was achieved after 7 quenches and 2 T magnetic field level is acceptable for routine operation. Average liquid helium consumption was defined as 0.03 l/h. The electron beam is moving through the wiggler inside copper liner with temperature 20 K.

In the first weeks of May 2005, the Hard X-Ray Micro-Analysis beamline staff obtained monochromatic X-ray using radiation from the wiggler.

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