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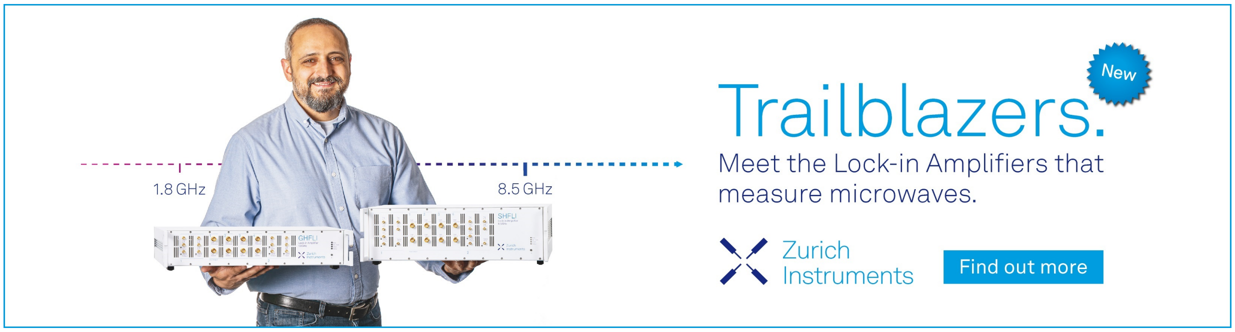

Construction and Tests of the 49-pole 3.5 Tesla Superconducting Wiggler for ELETTRA Storage Ring

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Abstract. The necessity of extending the useful spectrum of synchrotron radiation at higher energies (> 10 keV) for X-Ray Diffraction applications was the reason for developing and constructing a novel superconducting insertion device the Elettra storage ring. The superconducting wiggler with 45 full poles and a field strength of 3.5 T, 16.5 mm magnetic gap and a period of 64 mm has been developed and produced by the Budker Institute of Nuclear Physics SB RAS. This article describes some technical properties and characteristics of the wiggler as well as the results of the wiggler tests.

INTRODUCTION

The ELETTRA storage ring [1] is a third generation synchrotron radiation source operating at 2.0 and 2.4 GeV, with eleven ID straight sections and a maximum stored current of 320 (140) mA at 2.0 (2.4) GeV.

For the second Diffraction beamline a higher flux and brightness source was requested compared to the 57-pole 1.6 T multipole wiggler currently in use on the existing Diffraction beamline. A preliminary design study concluded that a superconducting multipole wiggler was an ideal source for photons in the 10-25 keV range. The contract for the detailed design and manufacture was placed with the Budker Institute of Nuclear Physics (BINP) in December 2001. The wiggler, shown in figure 1, was installed in the ELETTRA storage ring in November 2002 [2]. The main parameters of the wiggler are shown in Table 1.

TABLE 1. Main Parameters of the 3.5 T Wiggler.

Parameter	Value	Parameter	Value
Field Direction	Vertical	**Field Structure**	¼, -¾, 1, -1, ..., 1, -¾, ¼
Peak Magnetic Field	3.66 T	**Working Magnetic Fields**	3.5 T
Transverse Field Homogeneity	$\Delta B/B < 5\cdot 10^{-3}$ at $x=\pm 10$ mm	**Pole Gap**	16.5 mm
Horizontal Aperture	81 mm	**Vertical Aperture**	10.7 mm
Period Length	64 mm	**Stored Energy at 3.5 T**	240 kJ
Working Temperature	4.2 K	**Total Mass of Cooled Part**	~1000 kg
Critical Photon Energy	9.3 keV	**Radiated Power (200 mA, 2 GeV)**	8.57 kW

MAGNETIC SYSTEM

The wiggler design is based on 49 superconducting dipoles. The field structure of the wiggler magnet is shown in Table 1. The magnet consists of 45 full field central dipoles with a field of B=3.5 T, two side dipoles with ¾B and two side dipoles with ¼B. Each dipole consists of two NbTi coils assembled symmetrically above and below the vacuum chamber.

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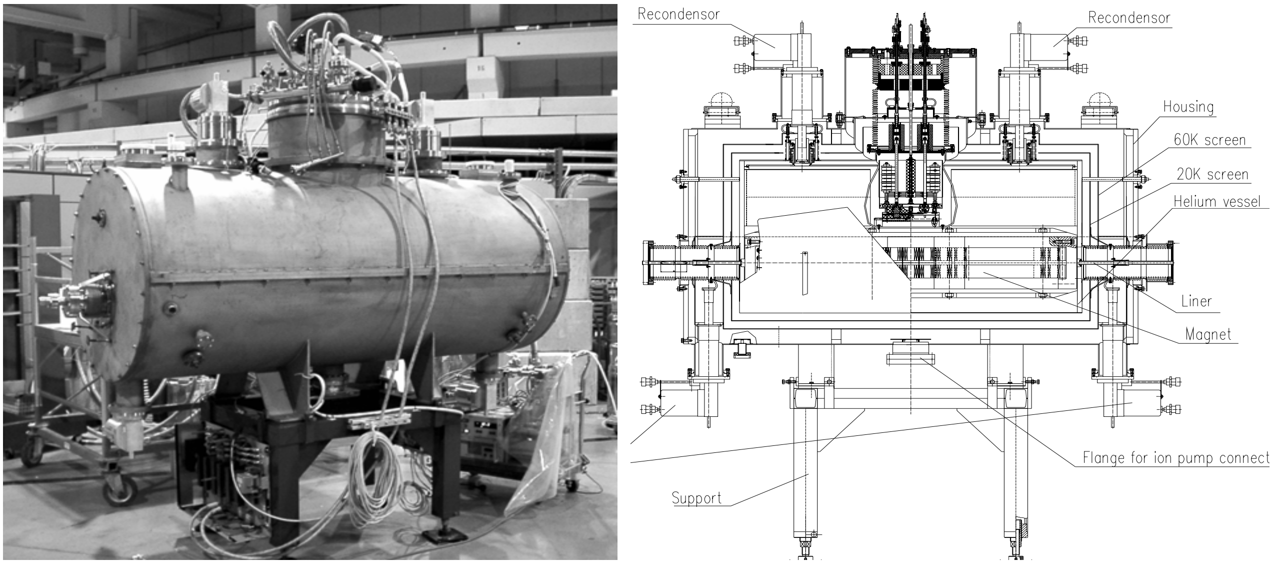

FIGURE 1. General view and sketch of the wiggler.

Superconducting NbTi wire with lacquer insulation was used to produce the wiggler coils. The parameters of the superconducting wire are: diameter 0.87 mm (0.92 with insulation), 8600 filaments in the Cu matrix (ratio NbTi:Cu = 0.43), critical current at 7 T - 380 A. The strong magnetic field on the wiggler axis is created by coils wound over the ARMCO-iron cores. The 45 central coils are made of two different sections which are wound one over the other. Each section is energized by two different currents to obtain optimal field-current characteristics.

The ARMCO-iron yoke is used to return the magnetic flux and to support the coils. The length of the magnet yoke is 1700 mm. The yoke includes two parts which are placed symmetrically above and below of the median plane of the wiggler. The dimension of the vertical magnetic gap between the coils is 16.5 mm and is guaranteed by non-magnetic stainless steel spacers with thickness of 8.25 mm.

Two independent power supplies feed the wiggler coils. The first power supply feeds both the inner and the outer sections. The second one is used only for the outer sections, so that both currents are summed up in the outer sections. The windings are connected in series outside the strong magnetic field region using a special procedure to reduce the resistance of each connection to less than 10^{-10} Ohm. The critical field value as a function of the superconducting wire current at 4.2 K is shown in Figure 2.

The use of two power supplies to feed the central and side coils gives the possibility to control the field integral to zero within the requested tolerance. Each superconducting section of the wiggler is protected by shunts with a resistance of 0.1 Ohm and cold diodes in order to prevent the coils from damaging during a quench.

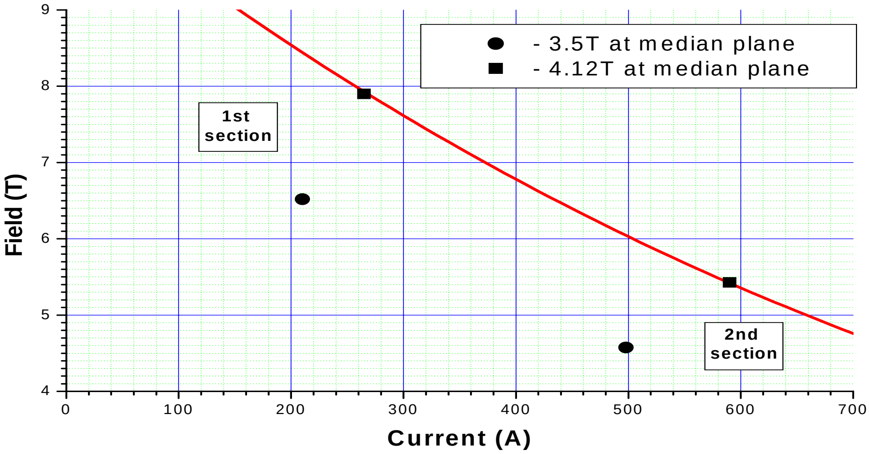

FIGURE 2. Critical magnetic field value vs SC wire current at 4.2 K (working point temperature).

CRYOGENIC SYSTEM

The scheme of the cryogenic system is shown in Figure 1. In order to reduce the irradiation heat flux from outside, the inner liquid helium vessel is surrounded by two screens. The temperature of the outside (inner) screen is 50 (20) K. In addition there is vacuum insulation between the two screens and the external warm stainless steel vessel. The helium vessel is hanged with four kevlar strips connected to the external cryostat vessel. These strips pass through the external vessel walls and are used for precise alignment of the magnet.

Two LEYBOLD cryo-coolers COOLPOWER 130 (15 W @ 20 K max on the second stage) are used for cooling the 50 K and 20 K screens. Two recondensers COOLPOWER 4.2M (1 W @ 4.2 K max on the second stage) are used for recondensing the liquid helium inside the cryostat and for cooling the 50 K screen.

The helium vessel is a stainless steel barrel with horizontally oriented axis. The diameter of the cylindrical shell of the barrel is 700 mm with a wall thickness of 4 mm and a length of 1750 mm. The total volume of the helium vessel is 620 l, the maximum volume of the liquid He inside the vessel is 400 l and the minimum volume of liquid helium for wiggler operation is 100 l. The magnet coils are connected permanently by the current leads which consist of two parts: HTSC ceramics current leads at the lower part, and ordinary brass current leads at the upper part.

WIGGLER VACUUM CHAMBER

The small vertical size of the wiggler magnetic gap (16.5 mm) doesn't allow for arranging room temperature beam vacuum chamber inside the wiggler cryostat. So the chamber of liquid helium volume at the temperature of 4.2 K is also used as the beam vacuum chamber. There is a special copper liner inside of the helium chamber, connected to the 20 K copper screen. The liner is used to prevent the electron beam from hitting the helium chamber. To avoid a thermal contact and to control the required gap between the liner and helium vacuum chamber, stainless steel pins are used. Bellow assemblies at both ends of the wiggler vacuum chamber are used for connection to the storage ring vacuum chamber.

WIGGLER TEST RESULTS

During the wiggler testing, the properly work of cryogenic components (coolers and recondensors), power supplies, hardware and software, vacuum equipment, diagnostic instruments and quench protection system have been demonstrated. Insulating vacuum during the measurements, provided by ion pump, was better than $1\div2\cdot10^{-7}$ mbar. About 700 liters of liquid nitrogen were used to cool down the magnet from room temperature to 90K, during 70-80 hours. 400 liters of liquid helium were spent to cool down from 90K to 4K, during 3-5 hours.

Four quenches of superconductivity have been produced after wiggler assembling at the ELETTRA site. The first quench occurred at field of 3.66 T (with currents 212.3 A and 280 A) at a pressure inside the helium vessel of 1 bar.

Two special power supplies fabricated by DANFISIK where used. During 72 h of long term testing at 3.5 T the stability of the currents was not worse than $5\cdot10^{-6}$, corresponding to an orbit stability not worse than 1 micron.

The time needed for ramping up by keeping the orbit distortion within 100 microns rms, is about 4 minutes and 30 seconds. This time may be decreased to 3 minutes and 30 seconds by increasing the current speed when the magnetic field is larger than 1.5 T.

The time for ramping down with orbit control is about 9 minutes and is limited by the damp diodes voltage. The horizontal displacement of the wire as a function of the field, measured by Wire Position Monitors (WPMs) during the ramping down are shown on Figure 3. WPM1-2 is the wire displacement on each side of the wiggler (corresponding to a 2 GeV electron beam displacement) in a horizontal plane perpendicular to the longitudinal coordinate.

There are two persistent current switches, which are connected in parallel to the magnet coils. These switches can close both current circuits. During persistent mode of operation the switches are in closed state (i.e. the heaters inside the switches are switched off). In this case, due to the strong coupling inductance and not zero resistance, there is a redistribution of the currents inside the coils. As a result, one current is increasing and the other decreasing during the free decay process. The magnetic field in the median plane is decreasing and the decay time depends on magnetic field level. As a example for field of 1.5 T, the decay time is equal to 4.4 years, for 3.5 T to 77 days. To compensate for this redistribution effect and to keep the first field integral close to zero, a special device called "magnetic flux pump" was proposed and installed. It gives the possibility to increase the decay time at 3.5 T to 175 days (corresponding to a field variation $\Delta B/B=2.4\cdot10^{-4}$ per hour) with beam orbit displacement within 1 μm.

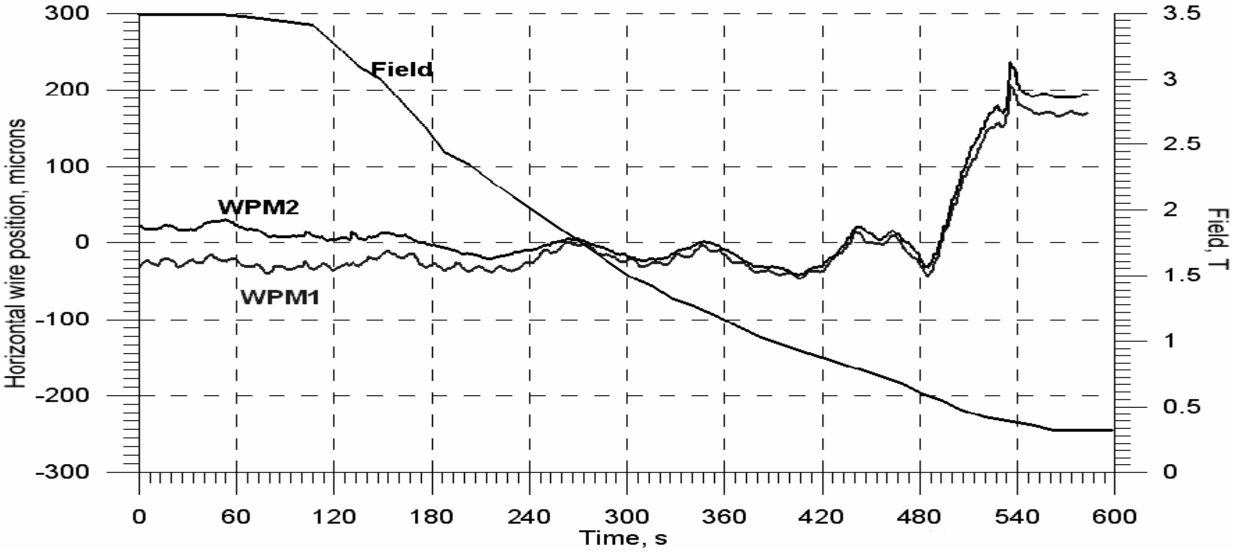

FIGURE 3. Behavior of the horizontal wire position during field ramping down at 2 GeV energy.

The measurements of the first and second magnetic field integrals have been carried out by the stretched wire method with a sensitivity $5*10^{-6}$ T*m/μm. The second field integral was found proportional to magnetic field with a maximum value equal to 3 $G \cdot m^2$ at 3.5 T.

The magnetic measurements of the wiggler were first carried out in a bath cryostat after magnet fabrication at Budker INP, then repeated in own cryostat during the Factory Acceptance Test and the Site Acceptance Test at ELETTRA. All these tests showed the good quality of the magnet manufacturing and assembling. Hall plate scans at field 0, 0.6, 1, 1.5, 2, 2.5, 3, 3.2, 3.4, 3.5 T have been carried out as well as scans at residual magnetic field after quench of superconductivity. The calculated (from magnetic measurements) sextupole component error is less than 10 T/m^2 at a field of 0.6 T and less than 100 T/m^2 at field 3.5 T. The measured rms peak field variation is about 1% at field 3.5 T.The measured field integral variation as a function of time (in persistent mode and flux-pump OFF) at 3.2 T is about 3±1 G*cm/min for the horizontal plane and 0±10 G*cm/min for the vertical plane.

The measured liquid helium consumption was: ~0.8 l/h in power mode at 3.5 T, 0.4-0.6 l/h in persistent mode at 3.5 T (in storage ring, without electron beam).

CONCLUSION

The development of the new superconducting insertion devices permits to increase the photon flux in the hard X-ray region spectrum. The presented multipole 3.5 T superconducting wiggler, produced at the Budker INP [3,4] is able to supply a photon flux of approximately $3*10^{14}$ photons/sec/mrad^2/(0.1%BW) with a critical energy of 9.31 keV, with an electron beam of 200 mA at 2 GeV.

In the autumn of 2002 this wiggler was successfully tested at the ELETTRA site and then installed in the storage ring. However initial measurements showed anomalous liquid helium consumption in presence of the electron beam: about 6 times higher than what measured at zero circulating current. This is believed to be due to an interaction between the copper liner holes and the electrons wake field. The Budker INP has now designed and constructed a new liner that will be installed and tested next November 2003.

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