SUPERCONDUCTING HIGH-FIELD WIGGLERS AND WAVE LENGTH SHIFTERS IN BUDKER INP

A.M. Batrakov, E.A. Bekhtenev, V.M. Borovikov, V.K. Djurba, M.G. Fedurin, V.V. Repkov, G.V. Karpov, S.V. Khruschev, G.N. Kulipanov, M.V. Kuzin, V.K. Lev, N.A. Mezentsev, V.A. Shkaruba
Budker Institute of Nuclear Physics, SB RAS
Lavrentiev Ave.11, 630090 Novosibirsk, Russia e-mail: shkaruba@inp.nsk.su

Several high-field superconducting wigglers (SCW) and wavelength shifters (WLS) are fabricated in the Budker INP for generation of synchrotron radiation. Three-pole WLS with the magnetic field of 7.5 T are installed on LSU-CAMD and BESSY-II storage rings for shifting the radiation spectrum. WLS with the field of 10.3 T will be used for generation of slow positrons on SPring-8. Creation of a 13-pole 7 T wiggler for the BESSY-II and 45-pole 3.5 T wiggler for ELETTRA now is finished. The main characteristics, design features and synchrotron radiation properties of SCW and WLS created in the Budker INP are presented in this article.
PACS numbers: 41.60.ap, 07.85.Qe

1 INTRODUCTION

Last few years in the Budker INP several high-field superconducting wigglers (SCW) and wavelength shifters (WLS) used as insertion devices (ID) for storage rings are developed and fabricated for generation of synchrotron radiation (SR). Such devices are used for shifting the photon critical energy to the hard X-ray range due to a high magnetic field and for magnification of the photon flux with the use of many poles. This gives new possibilities for the existing SR sources and allows to conduct new experiments. In addition this ID can be used to control the emittance of the storage ring, to decrease the polarization time of electron or positron beam etc. In the Table 1 the main features of SCW and WLS which are produced by the Budker INP are presented.

2 MAGNETIC SYSTEM

Such devices as SCW and WLS are not the main elements of the storage ring lattice and do not reduce reliability of the machine. The compensation of the wiggler effects on beam dynamics has to be performed. One of the main demands for the wiggler field distribution is the minimization of the field integrals along the ID for closing rbit. Only the central pole of three-pole PLS-WLS [1] has a high-field level of 7.5 T and is used for generation of SR. Two side poles with a low-level field of 1.5 T are needed for closing the beam orbit. The side pole field level is selected as low as possible for spectral separation of SR from the central and the side poles to reduce contribution of the so-called "second source". Some inconvenience of using of three-pole wiggler is the deviation of the equilibrium electron orbit and shifting the radiation point at the different field level. Therefore for the next three-pole 7.5 T WLS (CAMD-WLS [2], BESSY-WLS [3] and BESSY-PSF) two additional usual steering magnets were placed at the both ends of the ID straight section for compensation of the orbit deviation. In this case the geometry of the SR experiments is not changed at any field level since the radiation point is fixed in the center of WLS. The distribution of magnetic field and electron beam orbit along the BESSY-WLS straight section are presented in Fig. 1.

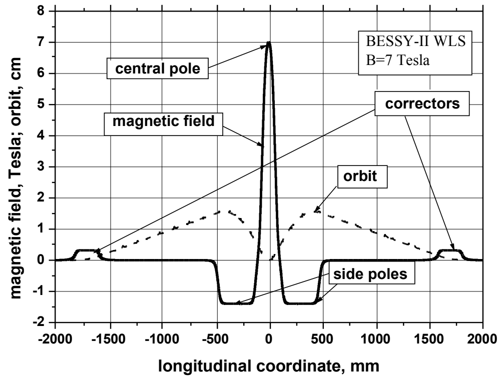

Fig. 1. The distribution of the magnetic field and electron beam orbit along the BESSY-WLS straight section.

The three-pole wiggler magnetic system (see Fig. 2) consists of two halves of an iron yoke with three superconducting dipoles which are located above and below of the vacuum chamber. The iron yoke is designed so that a whole magnetic flux is closed inside of the magnet and there are no stray magnetic fields outside of wiggler. The key element of three-pole wigglers is the high-field superconducting racetrack central pole with the iron core. The coils are reeled up from superconducting Nb-Ti wire with the diameter of 0.85 mm and impregnated with the epoxy compound. The critical current of the used wire is equal to 360 A at a field of 7 T. Each of the central coils is separated into two sections to optimize the field – current relationship and reach the maximum field. To feed the coils two independent power supplies are used. The inner and outer sections of the central coils and all side coils are powered by the first power supply with a current of ~150 A. The second power supply with a current of ~100 A feeds the outer section of the central coils. In this way the currents are summarized at the outer sections and the value of the current is equal to ~250 A. Thus each section is energized by the optimal current and there is a possibility for easy control of the first field integral to zero at any field levels. The magnetic field homogeneity of 10^{-4} at 7 T is obtained at the central pole as a result of shimming in the aperture of the magnet by special iron plates. For bandaging the superconducting windings inside of the iron yoke we used two pairs of wedges produced from a material with a low heat extension factor (e.g. invar). Different thermal contraction of the used material makes it possible to compress the superconducting winding during cooling down to the liquid helium temperature. Such design makes it enable to achieve a maximum current of about 90% of the short sample current.

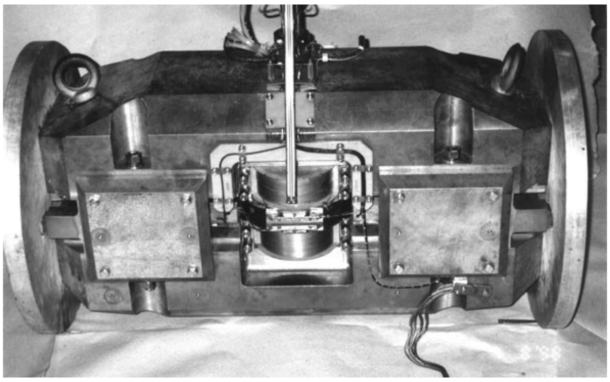

Fig. 2. Magnetic system of three-pole BESSY-WLS.

The installation of the wiggler with a field of about 10T on the Spring-8 with the electron beam energy of 8 GeV makes it possible to create a slow positron source of high brightness [4]. To obtain the magnetic field higher than 8 T it is needed to use a Nb_3Sn superconducting wire with a higher critical current. The technology of manufacturing the high-field superconducting Nb_3Sn windings of the racetrack type was developed and tested successfully. A rectangular Nb_3Sn tie 1.45x 0.85 mm^2 in size was used for manufacturing the inner section of the central pole for the 10 T wiggler for Spring-8. For protection of a Nb_3Sn wire from degradation during the quenching the current distribution inside of the coils is matched so that two outer Nb-Ti sections are closer to the critical condition than the inner Nb_3Sn section. In 2000 the wiggler was assembled and tested at the Spring-8 site and the maximum field of 10.3 T was achieved.

The photon flux generated by wigglers is proportional to the number of the wiggler poles. So the multi-pole wigglers are used for enhancement of the X-ray flux. The multi-pole 7 T wiggler with 13 poles and 3.5 T one with 45 poles are produced now by the Budker INP for BESSY-HMI and ELETTRA, respectively. In 2001 the short prototypes of these wigglers with three central poles and four side poles used for orbit compensation were successively tested. The maximum fields of 7.6 T on the magnetic gap of 19 mm were obtained for the BESSY-HMI prototype. For ELETTRA prototype a maximum field of 3.7 T on the 16.5-mm magnetic gap was achieved. The full-size multi-pole wigglers mentioned above will be finished and installed on the storage rings in 2002.

3 CRYOGENIC SYSTEM

The superconducting magnets are inserted into special liquid-helium cryostats. In the first cryostat for PLS-WLS with liquid helium consumption of 3 liter per hour there was only one copper thermal screen cooled by liquid nitrogen. A whole series of improvements was carried out for reduction of liquid helium consumption. The view of another cryostat for BESSY-WLS where heat inleakage into the helium vessel from the outside is minimized is shown in Fig. 3.

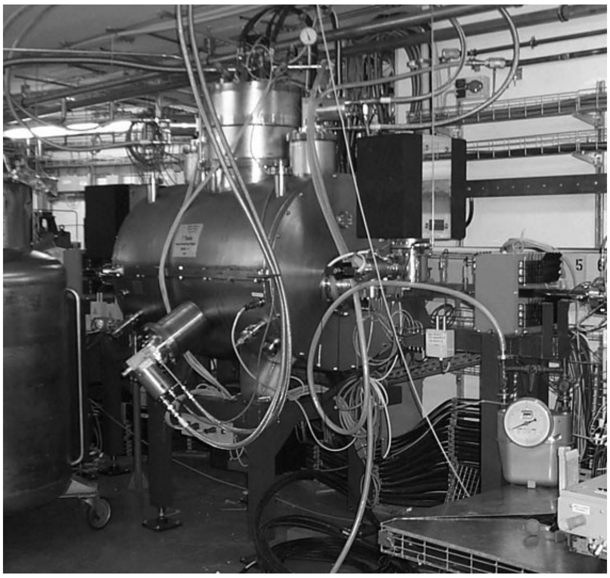

Fig. 3. View of BESSY-WLS on the BESSY-II storage ring.

The liquid helium vessel is surrounded by two screens to reduce the heat flux into the helium volume. The outer and inner screens are wrapped by 30 and 10 layers of super-insulation, respectively. The screens with the temperature of 60 K and 20 K are cooled by a two-stage cooling machine with a cooling power on the stages of 115 Watt and 15 Watt, respectively. There is the vacuum insulation with the value of 10^{-7} Torr between the helium vessel and the external warm stainless vessel.

This insulating vacuum of the cryostat is independent and completely separated from the vacuum system of the storage ring. The special cevlar suspensions are used for hanging the helium vessel and the screens to minimize heat inleakage. The ends of the suspensions pass through the external vessel walls and are used for precise alignment of the magnet position. Two pairs of HTSC ceramic current leads which connected with the optimized cooper current leads are used to energize the magnet coils. The using of ceramic current leads permits to decrease heat inleakage 5 times less compare with optimized cooper current leads. Heat flux coming along the current leads from the upper flange due to thermal conductivity is taken off by connecting of cooper current leads to the cooler stages through the special ceramic contact. After energizing the magnet coils are closed by persistent current superconducting switch and wiggler goes into "freezing current" operation mode.

Then a special system controlled by computer makes mechanical disconnection of cooper current leads from HTSC ones inside of the cryostat. The consumption of the liquid helium at the mode of disconnected current leads is equal to 0.12 liters per hour. It enables to refill liquid helium in the cryostat not often then 1 time per month. To compensate the current decay in the "freezing current" mode the magnetic field is stabilized with accuracy of 10^{-4} at 7 T by feedback system with using of NMR probes and special transformers called magnetic flux pumps [5]. To decrease the current decay a special welding technique was developed for decreasing of contact resistance between the superconducting coils.

Table 1. Main parameters of SCW and WLS produced in BINP

	Magnetic field, T Max/normal	Number of poles	Pole gap, mm	Main Pole length, mm	Magnetic length, mm	Vertical aperture, mm	Radiation power, kW
PLS-WLS (Korea), 1995	7.68 (7.5)	1+2	48	170	800	26	3.6
CAMD-WLS (USA), 1998	7.55 (7.0)	1+2	51	172	972	32	5.3
SPring-8 (Japan), 2000	10.3 (10.0)	1+2	40	200	1042	20	100
BESSY-WLS (Germany),2000	7.5 (7.0)	1+2	52	172	972	32	13
BESSY-PSF (Germany),2001	7.5 (7.0)	1+2	52	172	972	32	13
BESSY-HMI (Germany),2002	7.67 (7.0)	13+4	19	74	1360	14	60
ELETTRA (Italy), 2002	3.7 (3.5)	45+4	16.5	32	1680	11	8.8

4 CONCLUSION

The installation of the high-field WLS and SCW as insertion devices enables one to improve characteristics of the storage ring for conducting new experiments with hard X-ray. Design of all the high-field wigglers manufactured by Budker INP has much in common. However, these wigglers do not repeat each other but have their own distinctive features, defined by specific requirements of concrete SR users.

REFERENCES

1. A.V.Grudiev et al., Superconducting 7.5 Tesla wiggler for PLS // *NIM*. 1995, Vol. A359, No. 1-2, p. 101-106.
2. V.Borovikov et al., Superconducting 7 T wiggler for LSU-CAMD // *Journal of Synchrotron Radiation*. 1998, v. 5, Part 3, p. 440-442.
3. V.M.Borovikov et al. Superconducting 7 T Wavelength Shifter for BESSY-II // *NIM*. 2001, v. A467, No. 1-2, p.181-184.
4. A.Ando et al. Proposal of the high magnetic field superconducting wiggler for slow positron source at SPring-8 // *Journal of Synchrotron Radiation*. 1998, v. 5, Part 3, p. 360-362.
5. V.M.Borovikov et al., Precise NMR measurement and stabilization system of magnetic field of a superconducting 7 T wavelength shifter // *NIM*. 2001, v. A467, No. 1-2, p. 198-201.