SUPERCONDUCTING WAVE LENGTH SHIFTERS AND MULTIPOLE WIGGLERS DEVELOPED IN BUDKER INP

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Abstract

Budker INP has almost 25 years experience on designing and manufacturing of superconducting specialized magnetic systems for generation of synchrotron radiation such as high-field superconducting wigglers (SCW) and wavelength shifters (WLS). Three-pole WLSs with the magnetic field of 7.5 T was installed on LSU-CAMD and BESSY-II storage rings for shifting of radiation spectrum. WLS with the highest field of 10.3 T was fabricated and delivered to Spring-8 site and will be used for generation of hard γ-ray for slow positrons source of high brightness on SPring-8. Two multipole wigglers 17-pole 7 T wiggler for BESSY-II and 49-pole 3.5 T wiggler for ELETTRA now are under developing. The main characteristics, design features and synchrotron radiation properties of SCW and WLS created in Budker INP are presented in this article.

1 INTRODUCTION

Last few years several high-field superconducting wigglers (SCW) and wavelength shifters (WLS) which used as Insertion Devices (ID) for storage rings are developed and fabricated for generation of synchrotron radiation (SR) in Budker INP. Such devices are used for shifting of photon critical energy to the hard X-ray range due to high magnetic field and for increasing of photon flux by using 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 storage ring, decrease the polarization time of electron or positron beam and others. In the Table 1 the main features of SCW and WLS which are produced by 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 but such effect as tune shifts, beam dynamic reduction etc should be compensated with use external magnetic elements. One of the main demands for the wiggler field distribution is the minimization of the field integrals along the ID to avoid closed orbit disturbance. Only the central pole of three-pole PLS-WLS [1] has high-field level of 7.5 T and used for generation of SR. Two side poles with low-level field of 1.5 T are needed for closing of 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 deviation of the equilibrium electron orbit and shifting of the radiation point at the different field level. Therefore for the next three-pole 7 T WLS (CAMD-WLS [2], BAM-WLS [3] and PSF-WLS) 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 BAM-WLS straight section is presented in Fig.1.

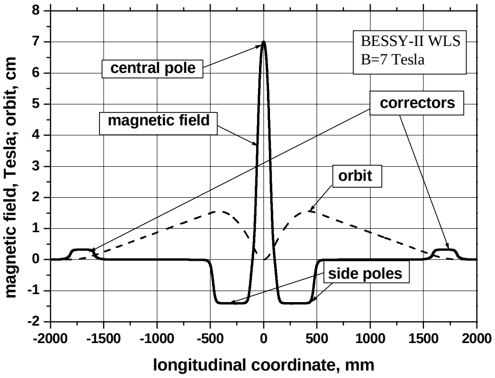

Fig.1: The distribution of magnetic field and electron beam orbit along BAM-WLS straight section

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 whole magnetic flux is closed inside of the magnet and there are no stray magnetic fields outside of wigglers. The key element of three-pole wigglers is high-field superconducting racetrack central pole with the iron core. The coils are reeled up from superconducting Nb-Ti wire with diameter of 0.85 mm and impregnated with epoxy compound. The critical current of 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 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 the current of ~150 A. The second power supply with the 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 current is equal to ~250 A. Thus each section is energized by the optimal current and there is a possibility of easy control of 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 of superconducting winding inside of the iron yoke it is used two pairs of wedges produced from material with 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 the maximum current about of 90% of short sample current.

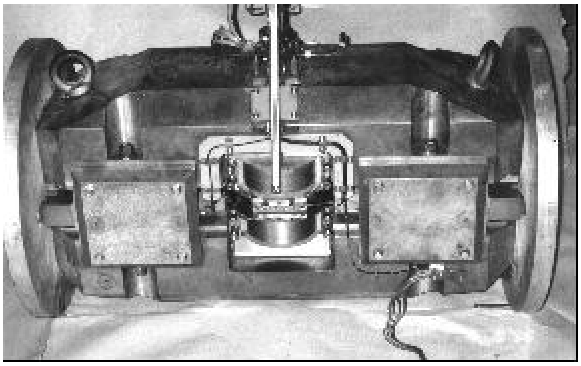
Fig.2: Magnetic system of three-pole BAM-WLS

The installation wiggler with the field of about 10T on Spring-8 with the electron beam energy of 8 GeV makes it possible to create slow positron source of high brightness [4]. To obtain magnetic fields higher than 8 T it needed to use a Nb_3Sn superconducting wire with a higher critical current. The technology of manufacturing of 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 of the inner section of the central pole for the 10 T wiggler for SPring-8. For protection of Nb_3Sn wire from the degradation during the quench 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. Multi-pole 7 T wiggler with 13 poles and 3.5 T one with 45 poles of full field are under production now by Budker INP for HMI-BESSY and ELETTRA, correspondingly. In 2001 the short prototypes of this wiggler with three central poles and four side poles used for orbit compensation were successively tested. The maximum fields of 7.6 T on magnetic gap of 19 mm was obtained for HMI-BESSY prototype. For ELETTRA prototype the maximum field of 3.7 T on 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 a special liquid helium cryostat. In the first cryostat for PLS-WLS with liquid helium consumption of 3 liter per hour there was only one cooper 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 outside is minimized is shown in Fig.3.

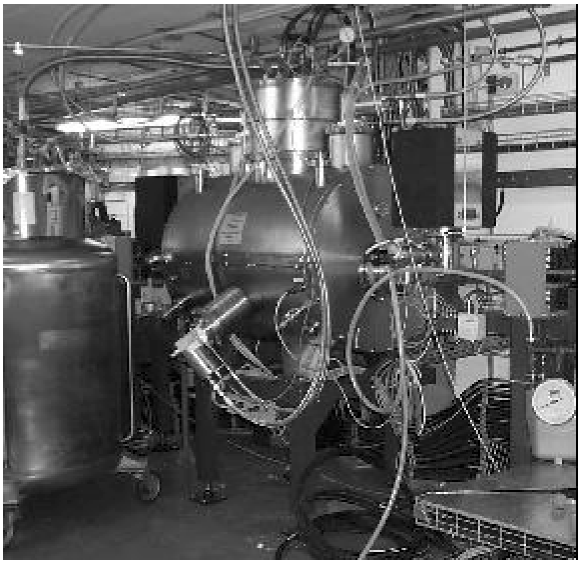
Fig.3: View of BAM-WLS on BESSY-II storage ring

The liquid helium vessel is surrounded by two screens to reduce the heat flux into helium volume. The outer and

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, kWatt
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

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 two-stage cooling machine with the cooling power on the stages of 115 Watt and 15 Watt, respectively. There is vacuum insulation with the value of 10^{-7} Torr between the helium vessel and an 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 of 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 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 go 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 Tesla 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.

4 CONCLUSION

Budker INP actively develops manufacturing of high-field superconducting wigglers and wavelength shifters. Design of high-field wigglers has much in common. However, these wigglers don't repeat each other but have their own distinctive features, defined by specific requirements.

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