9 TESLA SUPERBEND FOR BESSY-2

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Abstract

BESSY operates a 3-rd generation synchrotron light source in VUV to XUV region at Berlin-Adlershof. The main radiation sources in storage ring are special magnetic elements as undulators and wigglers. 3 superconducting shifters and one multipole superconducting wiggler are operating giving enhanced photon flux for 10-25 keV X-ray region. As the superconducting elements presently are located in straight sections, BESSY intends to exchange 4 of conventional room-temperature bending magnets by SC bends.

The report contains brief description of 9 Tesla superbend prototype as a candidate for replacing of conventional magnets of BESSY-2, which was designed, fabricated and tested in 2003 at Budker INP.

Main parameters of 9 Tesla superbend prototype as well as testing results are presented.

INTRODUCTION

It is well known the synchrotron radiation spectrum depends on both electron energy in the storage ring and magnetic field strength where electron is moving. In order to increase rigidity and intensity of radiation superconducting wigglers and shifters with high magnetic field are installing into straight sections of storage rings. But as a rule, straight sections are already occupied by such insertion devices as undulators while main workstations of 3 generation storage rings use radiation from traditional bending magnets. For storage rings with energy up to 2 GeV the spectrum from bending magnet is limited to energy of photons up to 25 keV and it strongly limits opportunities of realization of experiments. Besides for superconducting insertion devices like shifters and multipole wigglers there is a problem of the ‘second source’ which may limit to spatial and energy resolutions in experiments if it is required. From this point of view Superbend is free of these problems and it is rather cheap approach allowing considerably to expand an opportunity of experiments of already existing and expensive experimental stations, having expanded spectrum in rigid part. Lack of the Superbend is that in comparison with superconducting high field insertion devices it is a basic element of the storage ring and all its systems should be not less reliable in comparison with traditional magnetic elements in the storage ring.

The idea of creation of superconducting bending magnet with a high field for replacement of traditional warm magnet in already existing SR sources was aroused in Budker INP since 1989 [1-2] In 1992 prototype of superconducting bending magnet with working field of 6 Tesla was fabricated and successfully tested in Budker INP. There was a decision to create a batch production of such bending magnets for creation of family of compact SR sources consisting of superconducting and traditional bending magnets. Disorder of a financial system in Russia at that time unfortunately had brought in the corrective amendments and these plans could not be realized.

Break in this direction was made in USA in 2001: several superconducting bending magnets (Superbends) with a field above 5 Tesla [3,4] were made and installed on ALS storage ring.

Starting from 2001 9 Tesla Superbend prototype for BESSY-2 was started to fabricate in collaboration between Budker INP and BESSY. In August, 2003 Superbend was successfully tested in own cryostat and field 9.37 Tesla was obtained. At the present moment the work on minimization of heat in-leak into own cryostat are carrying out.

MAGNET SYSTEM

The SB magnet system is dipole consisting of two superconducting coils assembled above and below the vacuum chamber. The main parameters of the SB magnet are given in Table 1.

Table 1: The main parameters of the SB magnet

Vertical aperture, mm Horizontal aperture, mm	30 75
Pole gap, mm	46
Operating magnetic field, Tesla Maximum magnetic field, Tesla	3.3 - 8.5 9.38
Coil material	Nb_3Sn, NbTi
Edge angle, degree	1.3
Current in coil for 8.5 Tesla, A	264
Ramping time 0-7 Tesla, min Ramping time 0-9 Tesla, min	<5 <15
Eff. magnetic length along beam, m	0.1777
Bending angle, degree	11.25
Bending radius, m	0.905
Stored energy for 8.5 Tesla, kJ	180
Cold mass, kg	~1300

The SB magnet coil consists of five sections winding around ARMKO iron core. The first and second sections are wound from Nb_3Sn wire. The third section is wound from NbTi wire. The fours section is wound from NbTi wire and used for correction. The coil main parameters are given in Table 2. The ARMKO iron core has a shimming notch to obtain necessary transversal field homogeneity.

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Table 2: The coil main parameters

Coil Sections	Wire Type	Number of layers (turns in the layer)	Total Turns
1	Nb_3Sn (80%), d=1.24mm	10 (77, 76)	765
2	Nb_3Sn (50%), d=1.24mm	10 (77, 76)	765
3	Nb-Ti, d=0.92 mm	18 (105, 104)	1881
4 corrector	Nb-Ti, d=0.92 mm	4 (105, 104)	418
5 bandage	Stainless steel, d=1 mm	4 (95, 94)	378

Special bandaging system is used to prevent winding wire motion under pondermotive forces action. The bandaging system consists of bandaging section of the coil and stainless steel ring with 150 bolts. This bolts press on the bandaging section via four special form stainless steel plates. The sketch and photo of SB magnet coils with bandaging system are given in Figure 1,2. The ARMCO iron yoke is used to return the magnetic flux and to support the coils. The photo of the assembled superconducting bending magnet is given in Figure 3.

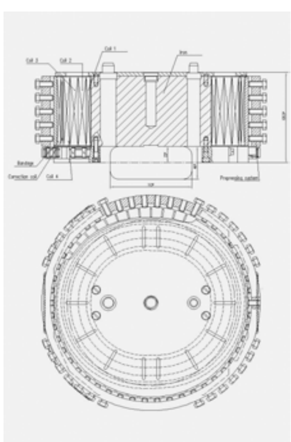

Figure 1: Sketch of assembled coil

Figure 2: Photo of assembled pole

Figure 3: Photo of assembled magnet

CRYOSTAT DESIGN

Superconducting magnet is inserted into special cryostat with liquid helium at temperature 4.2 K. The photo of the cryostat is presented in Figure 4. The cryostat is divided into two parts: upper and lower cryostats. The upper cryostat is used as liquid helium reservoir and for mounting of two cryocoolers and current leads. The superconducting magnet with vacuum chamber for electron beam is placed into the lower cryostat. Upper cryostat is designed as a storage volume of ~200 liters of liquid helium which needed for at least 7 days of working without refilling if liquid helium consumption is equal to ~1 l/h. Upper and lower parts cryostats are connected through a special neck. Inside the connecting neck the current leads for feeding magnet coils, diagnostic wires and liquid helium filling tube are passed. There are two temperature shields having the temperature of 15 K and 35 K between liquid helium volume and outer vacuum housing. The copper shields which are covered by multilayer superinsulation are cooled by two-stages Gifford-McMahon cryocooling machines with a total cooling power on each stages of 220Watt at 77K and 30 Watt at 15K correspondingly. The insulation vacuum of cryostat with a value of 10^{-7} Torr is independent and completely separated from the UH vacuum system of the storage ring. Beam vacuum chamber having room temperature is surrounded by copper shield connected with 35 K cryostat shield for reducing of heat flux to the helium vacuum chamber. In addition the first 35 K and second 15 K stages of cryocoolers hold the required temperature at the correspondent points of two optimized brass current leads and bellow helium gas outlet line. Magnet is energizing by current of 300 A through two optimized current leads. Each current lead consists of three parts: 1) outer optimized brass current leads located in insulating vacuum, 2) intermediate HTSC current leads located in the insulating vacuum 3) inner HTSC current leads located in the liquid helium volume.

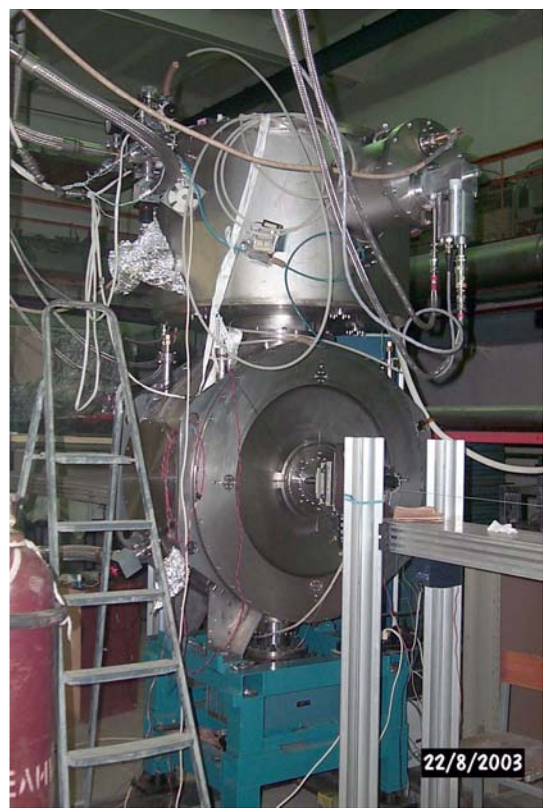

Figure 4: Photo of Superbend cryostat during magnetic measurements

The both liquid helium vessels and all screens are supported on special kevlar suspensions in order to minimize heat in-leak. The cryostat is equipped by 16 temperature sensors for monitoring of status all the cryostat systems during cooling down, routine working and warming up.

MEASUREMENT RESULTS

For checking of parameters of magnetic field of superconducting bending prototype magnet for BESSY II the number of magnetic measurement experiments were performed during in August 2003.

These measurements were performed for next values of magnetic fields: 3.3, 6.3, 7.0 and 8.47 Tesla.

For testing of quality of magnetic fields a special carriage was fabricated. Five Hall probes were mounted on the thin ceramic plate with transverse horizontal step of 8 mm. Plate was inserted in the carriage on few positions with different altitudes (z coordinates). Carriage was pulled though the vacuum chamber by step motors and vertical component of magnetic field was measured along beam trajectory with transversal horizontal displacement of –16 mm, -8 mm, 0 mm, 8 mm, 16 mm. Repeating such measurements for the different vertical coordinates, it's possible to obtain 3-D map of magnetic field distribution around electron trajectory. The measurement were performed for 450 points along beam trajectory (with 1 mm step), and for 6 positions in vertical direction (with 1 mm step in vertical direction). Every measurement includes acquisition of 5 Hall probes placed in transverse direction with 8 mm distance. The results of this profiling for different values of maximal magnetic fields are presented on the Figure 5.

Table 3: Multipole component in the center of magnet

Multipole of order n	Skew component value	Normal component value
Dipole n=1, T	0	8.4703
Quadrupole n=2, T/m	0.558	-0.048795
Sextupole n=3, T/m2	-0.243	-21.5E
Octupole n=4, T/m3	363.09	34.873

These data are quite enough to make analysis of nonuniformity of field and for estimation of multipole contributions. The results of multipole expansion of data mentioned above are presented on the Table 3.

The field distribution in median plane transversal to beam trajectory in the magnet center is presented on Figure 6.

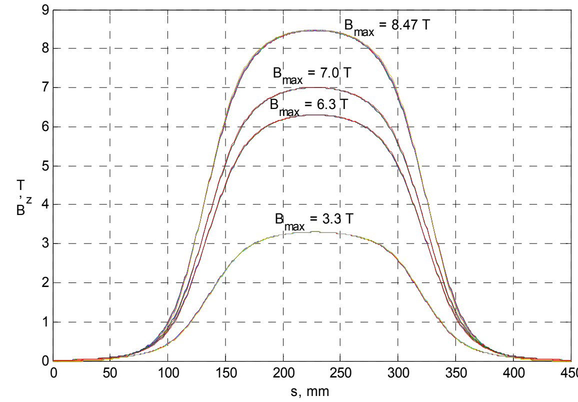

Figure 5: The longitudinal profiles of magnetic field of the magnet (calculated and measured data).

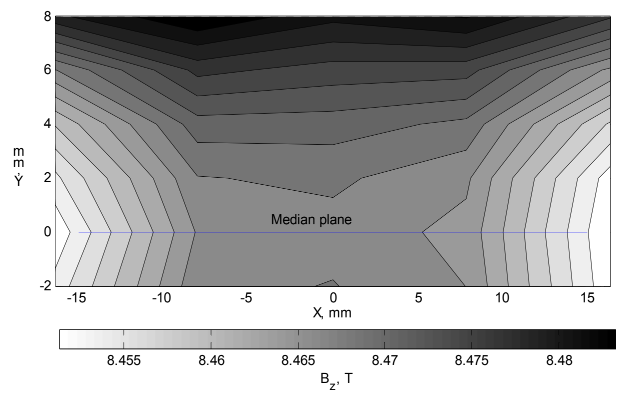

Figure 6: Transverse distribution of magnetic field in the center of the magnet.

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