SUPERCONDUCTING INSERTION DEVICES FOR SYNCHROTRON HARD X-RAY AT SRRC[+]

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Abstract

A project to install many high field superconducting insertion devices in short straight sections, such as the injection section, the RF cavity section, and between the arcs, has been launched to enhance the hard X-ray source of the 1.5 GeV storage ring at the Synchrotron Radiation Research Center (SRRC) in Taiwan. At present, a 6 T wavelength shifter with a 1.5 W cryocooler is installed in the injection section. One 3.2 T multipole wiggler with a 6 cm period and 32 poles has been designed and will be installed in the same straight section of the RF cavity. Meanwhile, the feasibility of installing three 3.5 T multipole wigglers in the short straight section between two bending magnets is studied. Therefore, this article discusses issues in optimization of the photon spectra, the design of magnet, the hardware interface, the cryogenic system and beam dynamics effect.

1 INTRODUCTION

The SRRC storage ring has four 6 m long straight sections in which the insertion devices are installed. Currently, the four insertion devices installed in the storage ring include a W20 wiggler, U5, U9 and EPU 5.6. Therefore, no extra straight section is used for installing any insertion device. However, R&D of superconducting insertion devices, including a 6 T superconducting wavelength shifter (SWLS) [1] and a 3.2 T superconducting multi-pole wiggler with a 6 cm period (SMPW6), has recently begun, in response to the growing demand for X-ray research. In May 2002, the SWLS was installed in an 83.5 cm free space between the third and fourth kicker magnet in the injection section. The magnet length with cryostat vessel is only 61 cm. The SMPW6 has a total length of 140.4 cm and locates at the down-stream of the superconducting RF cavity in the fourth section. The SMPW6 with 32 poles will be installed in 2003. Meanwhile, three 0.95 m long superconducting multipole wigglers with holmium poles, dubbed SMPW5, is planned to be installed in the short straight section between the arcs of the bending magnet in 2005.

Table 1 lists the main parameters of the superconducting insertion devices. Figure 1 shows the spectrum flux after the installation of the superconducting insertion devices has been enhanced. The flux of hard X-rays at 15 keV was 15 times larger than that from W20. For these superconducting insertion devices, a cryoplant will be built to provide the LHe for the superconducting magnets. Meanwhile, the cryoplant can be switched to provide LHe for superconducting RF (SRF) cavity, to support backup for the damage and maintenance of the SRF cryoplant.

Table 1: Main parameters of the superconducting insertion devices

	SWLS	**SMPW6**	**SMPW5**
B_{max}	6.0 T	3.2 T	3.5 T
λ (cm)	---	6.0	5.0
Pole gap	5.5 cm	1.8 cm	1.4 cm
Pole No.	1	32	18
Aperture	10 x 2.0 cm^2	8 x 1.2 cm^2	12 x1.2 cm^2
Total length	83.5 cm	140.4 cm	95 cm
Deflection K	---	17.9	16.3
Cooling method	Conduction by Cryocooler	Direction by LHe pool	Conduction by LHe
Pole material	Iron	Iron	Holmium

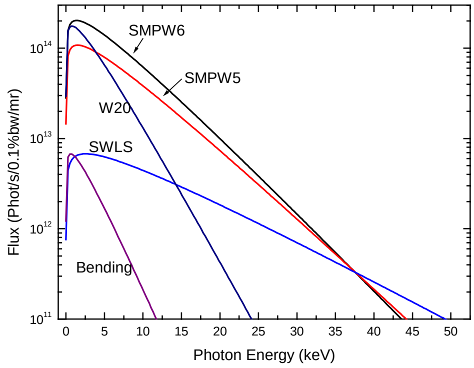

Figure1: The photon flux calculation for different insertion devices and bending magnet in SRRC storage ring.

2 R&D OF SUPERCONDUCTING INSERTION DEVICES

SRRC is experiencing an increasing demand for intensive hard-X-rays for experiments in X-ray absorption spectroscopy, X-ray scattering/diffraction and

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protein crystallography, especially in the field of biology. Accordingly, many superconducting insertion devices have been developed. The design concept and issues surrounding SWLS, SMPW6 and SMPW5 are discussed below.

2.1 Superconducting wavelength shifter

A compact cryogen-free SWLS has been designed, constructed and installed in Taiwan's light source, because of the limited space in the injection straight section. This SWLS, 610 mm long and with a warm bore gap of 20 mm (and coil gap of 55 mm), consists of three pairs of racetrack NbTi superconducting coils [1]. A 1.5 W Gifford-McMahon cryocooler is used to simplify operation and maintenance. A flexible S-shape OFHC multi-sheet assembly was constructed to connect the magnet to the 4 K stage of the cryocooler, to prevent vibration caused by the cold head of the cryocooler. Laminated return iron yokes with insulating epoxy and separated aluminum supporting blocks with insulating kapton, were constructed to suppress eddy currents. A maximum magnetic field of 6.5 Tesla was generated at the central pole.

When the magnet is operated at no excitation current and with LHe (without LHe), the temperatures of the lower and the upper coils are 3.6 K (4.0 K) and 4.7 K (7.2 K), respectively, under a 5 psig LHe vessel pressure. The temperatures of the first and second stage of the cryocooler are 53 K and 3.5 K, respectively. However, the hot end of the HTS current lead is 70 K at an excitation current of 260 A. Consequently, the SWLS is a cryogen-free operation in Liquid nitrogen but still has a LHe boiling-off rate of 0.2 L/h. If the lower and upper OFHC copper plates are welded together to reduce the thermal contact resistance, then the temperature of the upper coil will be under 4.4 K and no LHe boils off. Two bipolar power supplies with four HTS current leads, charge and discharge the magnet system and nullify the first field integral. The nominal current slew rate is set at 0.3 A/s. However, the maximum slew rate can exceed 0.5 A/s. A maximum field strength of 6.0 T can be obtained without training the magnet.

Two pairs of electromagnets located at each end of the magnet for multipole shimming and correcting the trajectory. The upstream one is for horizontal correction and the downstream one is for vertical correction. Consequently, the normal (skew) multipole components, –20 (-20) G-cm, 40 (13) G, -70 (-40) G/cm, -4 (0.5) G/cm^2 are all close to specification. The current of the side pole power supply is 1 A more than that of the central pole power supply in the design stage. Consequently, the integral field measurement showed that a 1.3 A of side pole power supply is required to adjust the first integral field strength to zero. Commissioning result shows that the SWLS can be operated in full field strength (at 6 Tesla) injection.

2.2 Superconducting multipole wiggler

An SMPW6 is planned to be installed in the residual space of the superconducting RF cavity straight-sections. The SMPW6 is quite rather close to the down-stream superconducting RF cavity. Hence, the leakage magnetic field trapped on the wall of superconducting RF cavity from the magnet must be reduced to 50 mG to maintain a high Q value and thus prevent the quenching of the RF cavity. Meanwhile, any vibration induced on the superconducting RF cavity is forbidden, and so the conduction cooled by cryocooler is instead directly cooled using the LHe bath. A 1mm thick 80 K stainless steel beam duct guides the electron beam and to reduce the heat load to 4.4 K. However, the beam duct (1 m long less than 80 K and 0.2 m long between 300 K and 80 K) has a heat load of 5.7 W [2,3] from the electron image current and 1.8 W from the conducted heat. However, the skin depth of the gold under SRRC's machine operating conditions is approximately 1 μm; the stainless steel beam duct is electroplated with 5 μm of gold to ensure that the heat load from electron image current can be ignored. Consequently, the heat load from the image current and that due to thermal conduction is changed by 0.11 W and 1.94 W, respectively. Finally, when SMPW6 is operated in the storage ring, an extra 0.11 W heat load is produced to the 80 K beam duct.

The total length, including that of the taper flange of SMPW6, is 140.4 cm. Thus, the maximum numbers of poles is 32, with a pole gap of 18 mm, and the nominal vertical peak field strength is 3.2 T. It has the capability to reach 3.5 T. The magnet will be operated in an LHe bath with a close cycle cryogenic system. The LHe consumption rate will be 2.5 L/h for 4.4 K. Even pole design was selected for SMPW6, since small multipole components can be easily obtained. However, the large trajectory offset can be adjusted almost to zero, by optimizing the end pole design. Therefore, the main power supply charges all 64 coils in series to produce the nominal peak field. The trim power supply is connected to the two side coils to nullify the first field integral. After the side pole is optimized, the trim power supply is nearly zero and zero first and second field integrals are obtained.

Meanwhile, the free space in the very short straight section between the two bending magnets is 95 cm. The design concept of the short superconducting multipole wiggler, SMPW5, achieves the highest possible both of field strength and pole numbers. Therefore, the holmium poles and conduction-cooled with LHe vessel are selected. In the preliminary design and calculation, the peak field is B_o= 3.5 T at an operational current density of 680 A/mm^2 with a periodic length of 5 cm. The peak field on superconducting coil is B_s=4.5 T. Table 1 shows the parameters in this design. The design of the beam duct temperature will be 4.4 K. Therefore, the heat load from the image current should be carefully removed by electroplating with gold. Meanwhile, the thermal conducting heat load from 300 K and 80 K to 4.4 K will also be critically important. The conducting heat load is reduced by the intersection of low temperature GHe, LN_2 and by step electroplating with gold.

3 IMPACT OF SUPERCONDUCTING ID ON THE STORAGE RING

The SWLS was installed in the free space between the third and fourth kicker magnets in the injection section. The impact on the storage ring with SWLS was discussed [4]. The SMPW6 and SMPW5 will be installed down-stream of the superconducting RF cavity in the fourth section (shown in FIG. 2), and in the short straight section between the two bending magnets (shown in FIG. 3), respectively. The SMPW5 is between the sextupole magnet (SF) and the second bending magnet (BM2) in the Triple Bend Achromat (TBA) lattice. Three SMPW5s will be installed in the second, fourth, and sixth sections. The presence of the superconducting wigglers and superconducting wavelength shifter introduce further distortion of the lattice optics, tune shifts, shrinkage of dynamics aperture, and increase of the beam emittance, etc. It is found from the simulation, the superconducting wiggler located in the RF straight section reduces dynamic aperture substantially. The simulation result shows the vertical dynamic aperture can be reduced to (+/-) 6mm. Furthermore three superconducting wigglers in the arc can increase emittance by 60%. Installing these insertion devices will cause reduction of lifetime, dynamic aperture and the injection efficiency. Therefore, careful engineering tolerance control and some supplementary adjustments of the whole accelerator systems are deemed necessary.

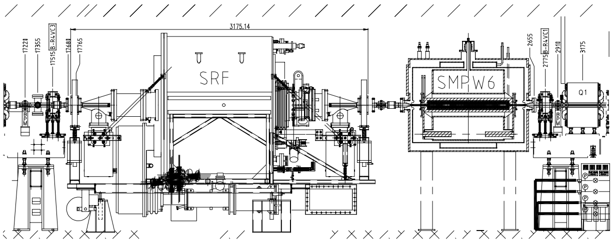

Figure2: SMPW6 locates at the down stream of the superconducting RF cavity.

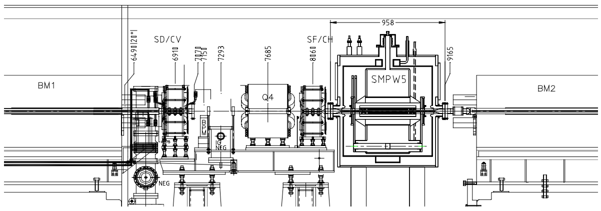

Figure3: Three SMPW5 magnets will locate at the down stream of the sextupole magnet and the upstream of BM2.

4 CRYOGENIC SYSTEM FOR MAGNETS

Five superconducting insertion devices will be installed in the storage ring. Therefore, a cryoplant will be constructed to provide LHe for five superconducting magnets. This system also provides emergency backup for the SRF cryogenic system. Its capacity is 255 W at refrigeration mode or 51 L/h at liquefier mode without using liquid nitrogen for cooling, and 450 W at refrigeration mode or 100 L/hr at liquefier mode with liquid nitrogen. The LHe consumption of each magnet is assumed to be around 2.5 L/h. There will be a 120m main transfer line and five 6m long flexible sub-transfer lines for helium supplying to magnets. The heat loss on main transfer line (about 0.3 W/m) is 36 W, the one for the sub-transfer lines is 45W. The heat loss for the helium supply valves (two for each magnet cryostat) is estimated as 30W. The LHe consumption from the connection valves of transfer ports (about 1 W/piece with numbers of 26 pieces) for transferring LHe is 26 W. Thus the capacity requirement of the cryoplant is around 137 W plus 12.5 L/h. Therefore, the cryoplant has a chance to supply LHe to all five superconducting magnets without using liquid nitrogen.

5 CONCLUSION

This article investigation describes a novel means of creating many abnormal straight sections in which many extra superconducting insertion devices can be installed. These superconducting magnets include the wavelength shifter and multipole wiggler that can enhance the hard X-ray source of the middle and low energy 1.5 GeV storage ring. The photon flux from the superconducting wiggler can be three orders of magnitude greater than that from bending magnet and 15 times greater than that from W20 in the 15 keV photon energy region. Major work is being considered to replace the existing 1.8 T wiggler W20 with a superconducting Landau cavity to increase the lifetime and with a superconducting undulator to enhance the photon flux between the energy ranges of few hundred eV to several keV, respectively.

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