IN-ACHROMATIC SUPERCONDUCTING WIGGLER IN TAIWAN LIGHT SOURCE: INSTALLATION AND TEST RESULTS

C. H. Chang[#], C. S. Hwang, H. H. Chen, H.P. Chang, F. Y. Lin, M. H. Huang , T. C. Fan,

J. C. Jan, C. C. Chang, G. Y. Hsiung And J.R. Chen, NSRRC, Taiwan

Abstract

A 16-pole in-achromatic superconducting wiggler (IASW) has been installed and operated in the achromatic section of a 1.5 GeV storage ring to increase the generation of high flux X-ray photon beams for Taiwan Light Source (TLS), The 3.1 Tesla superconducting wiggler is operated in a 4.5-K liquid helium cryogenic system. This work describes the operation experience and test results of the in-achromatic superconducting wiggler.

INTRODUCTION

TLS storage ring is routinely operated with a top-up injection mode at a constant electron beam current of 300-mA. The storage ring is a six-fold symmetric triple bend achromatic lattice with six straight sections. Six long straight sections are filled with insertion devices, including four permanent magnet devices and two superconducting magnet devices. A 5-T superconducting wavelength shift and a 3.2-T superconducting wiggler currently operate successfully in the storage ring [1,2,3]. To further enhance the high flux X-ray photons in the TLS, the installation of three 16-pole superconducting wigglers in achromatic sections of the storage ring is planed. A 3.1-T IASW magnet with a period length of 6.1-cm has been presented to produce a high flux and brightness source in the 5-23 KeV range. This device can provide about 500 times more flux than a bending magnet source at photon energy of 15 keV. The short wiggler significantly enhances performance. This superconducting wiggler is constructed in-house, and has been installed in the achromatic section of the storage ring. An IASW magnet is currently successfully operated at a magnetic field strength of 3.1-T with electron beam energy of 1.5 GeV. Table 1 presents the main parameters of the device.

Table 1: Main parameters of the IASW magnet

Magnetic period (mm)	61
Pole gap width (mm)	19
Vertical beam aperture (mm)	11
Horizontal beam aperture (mm)	98
Total number of poles	16
Total length of wiggler (mm)	960
Peak field (T)	3.1

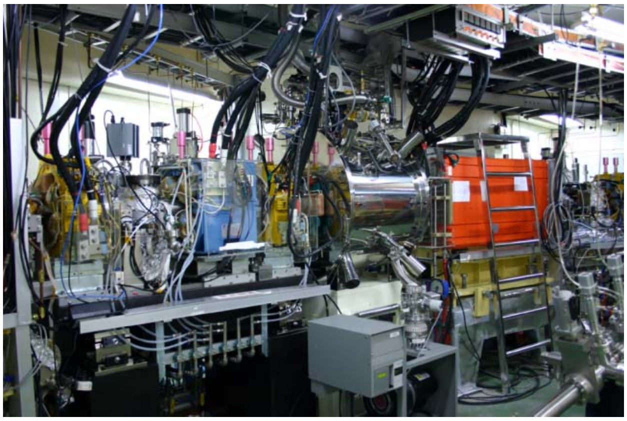

Figure 1: Schematic view of the IASW6 wiggler is installed near the second bending magnet of the triple bend achromatic section in the storage ring.

SUPERCONDUCTING WIGGLER

The achromatic section between the bending magnets has restricted space for a wiggler. The storage ring needs to modify to install the IASW insertion devices. An offset distance of 11-mm is maintained between the magnetic centre of the IASW and the ideal electron orbit centre to prevent the synchrotron radiation strike its cold walls. A new magnet girder for quadrupole and sextupole magnets is fabricated to reduce the magnet vibration in a low-frequency range. Additionally, two correcting magnets are installed at both ends of IASW magnet. Fig. 1 shows the IASW located between the first and second bending magnets in the achromatic section.

The magnet design is subject to several practical constrain the existed storage ring, including the magnet gap, magnet length, critical magnetic fields and current density in the superconductor [4]. Fig. 2 shows a cross-sectional view of the 960 mm long magnet. The vacuum chamber is 17 mm thick with an inside aperture for the beam of 11 mm height and 98 mm width. Hence, the vacuum chamber requires an inside width of at least 98 mm, to ensure that synchrotron radiation from the bending magnet cannot strike the cold walls at the end of wiggler. A simple aluminium extrusion of vacuum beam duct is adopted owing to its high mechanical accuracy and high thermal and electric conductivity. The pole and coils of the wiggler magnet are constructed with very small mechanical tolerances, and are assembled within aluminium mold. The coil positions are thus securely

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[#] chang@nsrrc.org.tw

fixed, and reducing amount of training occurred for the superconducting coils. The peak voltage on the coils is a significant design parameter which can be controlled from the external circuit when a quench is detected. The interlock system is designed to protect the coils of the magnet.

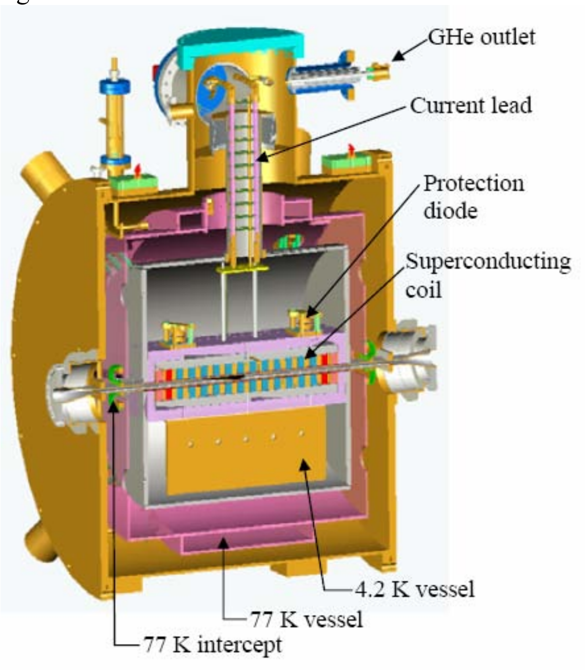

Figure 2: Cross sectional view of the 960 mm long IASW magnet.

The magnet was thoroughly tested before being installed. The magnetic fields of wiggler were measured by using a Hall-probe system in a cold temperature testing dewar. After training the coils, the magnetic field strengths were measured to attain the maximum field of 3.1-T at an excitation current of 265-A. The magnetic field profiles in longitudinal direction were examined close to the field calculation.

CRYOGENIC SYSTEM

Reliability and maintainability are the key requirements of a cryogenic system. The most conservative design would be to immerse the magnet in a bath of liquid helium. The cryogenic design includes the cryostat, transfer lines and cold gas return pipe. The cold magnet vessel is suspended in a 1-m diameter vacuum vessel using eight tension straps with four straps at each of the two ends. With this suspension arrangement, the center of cold magnet does not move during cooling. The pre-marks of magnet axis relative to the centre of 300K vacuum vessels are aligned at room temperature by adjusting the nuts at each end.

The cryostat of the wiggler magnet is designed to decrease the heat leak from thermal conduction and radiation from ambient to the cold magnet. The heat leak to the cold magnet directly influences the consumption rate of liquid helium. A critical clearance of 0.8 mm remains between the 4.2 K vessel and the 77 K beam duct for thermal shielding. Liquid nitrogen intercepts the beam duct in the longitudinally short space between the liquid helium vessel and the external warm beam duct, to lowering the consumption of LHe. The estimated liquid helium consumption of the cryostat is approximately 2.5 litres per hour.

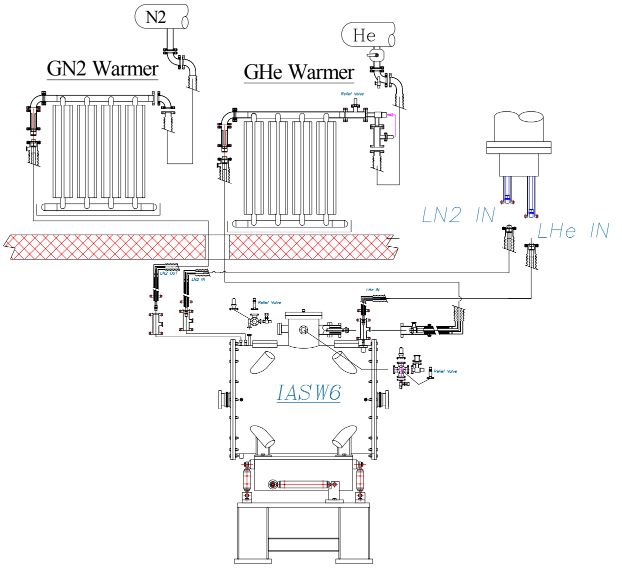

Figure 3: A simplified piping layout of the cold gas return and the liquid helium transfer system on the roof of the storage ring.

A superconducting wiggler needs a liquid helium cryogenic system in order to run at 4.5-K. A cryoplant with a capacity of 51 L/h at liquefier mode without LN2 cooling was built to produce LHe for three superconducting insertion devices and the superconducting radio frequency cavities. An additional cryoplant will operate independently for more superconducting magnets in the future development. Furthermore, the additional cryogenic plant also has an emergency backup system for the superconducting radio frequency cavities cryogenic plant [5]. The LHe of the wiggler cryostat is fed from a cryogenic supply with a 3.2-T superconducting wiggler and a 6-T SWLS magnet, which have operated since 2002.

Fig. 3 shows a simplified piping layout of the cold gas return and the liquid helium transfer system on the roof of the storage ring. A short vacuum shield flexible transfer line makes the connection between the cold valve and the wiggler cryostat. The cryogenic plumbing contains four separate circuits: LHe lines, gaseous helium warm return, LN2 line and gaseous nitrogen warm return. The process involves installing the superconducting magnet in the storage ring, and aligning it, and connecting the transferlines, and instrumentation cables and checking for vacuum leak. The complex operations of cleaning the particles large than 0.3 micron and removing the impurity from helium gas in the helium vessel are undertaken.

Particular care is taken to avoid quenching the magnet. Safety valves and burst discs are used to ensure the safety of the LHe and LN2 circuits. The evaporated helium gas is recycled to the compressor through the gas return pipe and is liquefied again using a refrigerator.

WIGGLER OPERATION

The cryogenic system was tested with a fully automated cool-down from ambient to 4.2 K. The magnet was refilled whenever its LHe level dropped below the 70% level. The cryogenic system cables closed cycle operation after initial cool down by adjusting the critical monitoring parameters for magnet protection. The maximum field of 3.1 T was reached gradually after 14 quenches. The wiggler operation was performed at up to 3.1-T at a current of 265-A, and was provided in the steady state without the electron beam. The wiggler emitted a synchrotron radiation of 2-kW power in a horizontal fan of 5.9 mrad at 300 mA electron beam. The temperatures of the vacuum beam duct were examined from the down-stream magnets and wiggler itself when first operating the wiggler with electron beam energy of 1.5 GeV. Synchrotron radiation did not significantly increase the temperature and pressure of the vacuum chamber in the inside wiggler. Testing results demonstrate the magnet meet its performance over a full field range from 0-3.1 T.

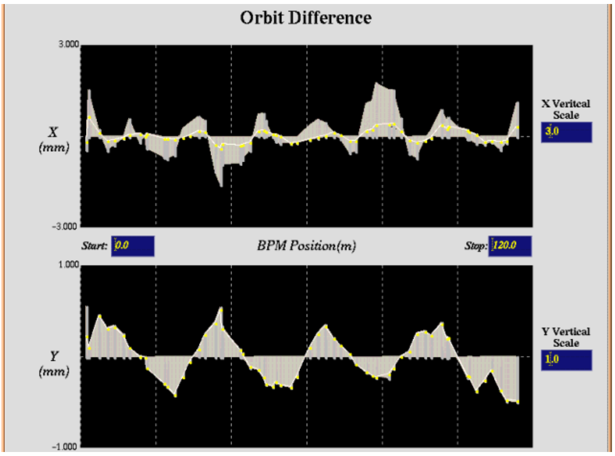

Figure 4: The maximum beam orbit change caused by the IASW magnet was small.

The top-up injection mode operation with 300 mA was tested successfully when the magnet was excited to a nominal current of 265-A. Fig. 4 reveals that the maximum beam orbit change caused by the IASW magnet was small. Fig. 5 plots the tune shift during the field ramping. The quadrupole magnets were adjusted to compensate the tune shift. The beam tests confirmed that beam injection is feasible with the IASW magnet excited at 3.1-T. No beam loss was observed during the field ramping, operation or quenches. Furthermore, the electron beam size was observed to be larger due to the increase of emittance.

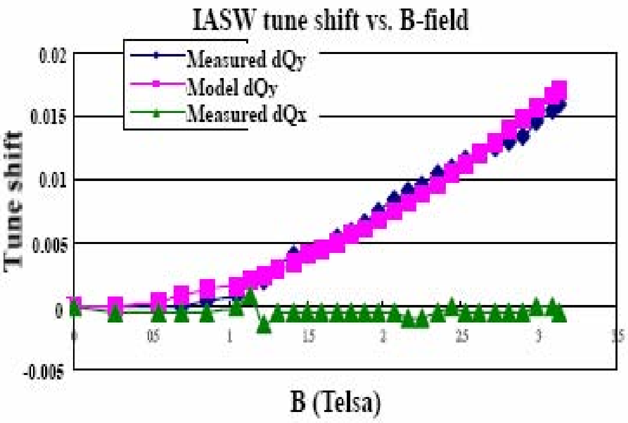

Figure 5: The tune shift during the field ramping.

CONCLUSIONS

A 16-pole in-achromatic superconducting wiggler has been successfully installed and commissioned at a magnetic field strength of 3.1-T with an electron beam energy of 1.5 GeV. The cryogenic system was thoroughly tested with a fully automated refill, and was found to permit a steady closed cycle operation. The electron beam testing revealed no beam loss was observed during the field ramping, operation and quenches. Two additional IASW wigglers are currently being tested and will be installed to enhance the storage ring performance during the next machine shutdown period.

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