DESIGN AND MANUFACTURE OF SUPERCONDUCTING MAGNET FOR THE WIGGLER IN SAGA-LS

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Abstract

A 4T superconducting wiggler for 1.4GeV synchrotron radiation facility Saga Light Source (SAGA-LS) was developed and manufactured. The wiggler consists of one superconducting magnet as main-pole and two normal conducting magnets as side-poles. The superconducting coils are wound with NbTi wires on iron poles, which are directly cooled by a 2-stage GM cryocooler. The structure of the wiggler is made for compactness and cryogen-free operation. This paper describes its magnet design and manufacturing processes.

INTRODUCTION

A superconducting wiggler as an insertion device of hard X-ray of energy up to 40keV has been studied at the synchrotron radiation facility SAGA-LS [1]. Stability, reliability, and economical operation are needed for the wiggler, in order to provide steady light source for users. Hitachi developed and manufactured its superconducting magnet, to meet the concept of the original wiggler design made by SAGA-LS.

The wiggler system was completed and installed in the synchrotron ring at SAGA-LS in March 2010. Its superconducting magnet and cryostat design, and product are reported in this paper.

SYSTEM CONFIGURATION

The wiggler consists of one main pole and two side poles. Its overall specification and pole configuration are shown in Table 1 and Figure 1 respectively. This is designed as C shape to be removable from the beam duct.

To obtain the required X-ray energy region, magnetic field of main pole is specified as 4T. Superconducting coils remain in operating temperature by conduction-cooling, in order to place the coils as close to the electron beam orbit as possible [2].

Table 1 Specifications of the superconducting wiggler

	Main Pole	Side Poles
Type	Superconducting	Normal
Number of poles	1	2
Magnetic field	4 T	0.97 T
Coil Shape	Racetrack	-
Wire of Coil	NbTi/Cu	Cu
Pole material	Pure Iron	Pure Iron
Cold Gap	82 mm	-
Warm Gap	35 mm	36 mm
Magnetomotive Force	450kA	13.2 kA

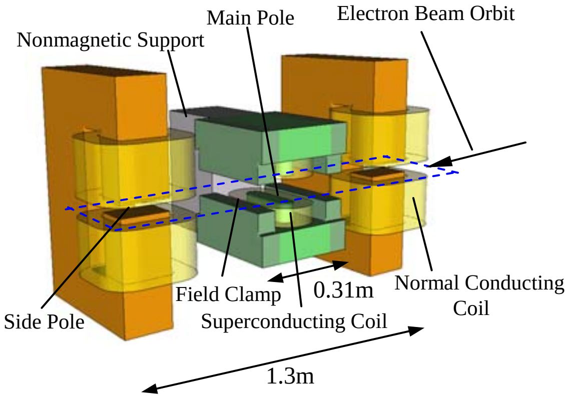

Figure 1: Pole configuration of the superconducting wiggler

Electron beam orbit is dependent on the magnetic field and magnet poles as shown in Figure 2. The orbit displacement as shown in the figure, must be less than 20 mm to minimize the heat generated inside the beam duct, which is caused by photons as a result of synchrotron radiation. This require magnetic field integral over the length to be within 0.7Tm. To minimize this, keeping the maximum magnetic field at 4T, special shape of magnetic pole is employed.

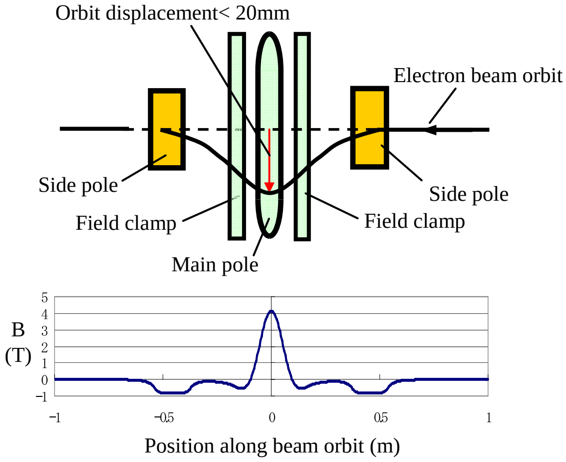

Figure 2: Pole configuration and electron beam orbit image with vertical magnetic field

MAGNET DESIGN

Coil and Iron Yoke Design

Superconducting coils of the wiggler are manufactured with established technology to consider the reliability and stability of the wiggler system. Table 2 shows the magnet specification and Figure 3 shows the dimensions of coil. The conductor is specified and manufactured for this wiggler. It is a NbTi/Cu monolithic conductor with a cross section of 0.9mm x 1.3mm including insulation.

Poles and yokes are made from electromagnetic soft iron. The conductor is wound on a racetrack-shape iron pole, and then they are impregnated with epoxy resin. Two coils are configured as C shape with thick iron yoke.

To reduce magnetic field integral of the main pole, width of the magnet pole is adjusted to limit the maximum magnetic field within the coil. Furthermore, field clamp is attached to the coil on each side, allowing a part of magnet flux to return, so that magnetic field integral of the main pole is effectively reduced keeping its required magnetic field. This can reduce the displacement of electron beam orbit less than 20mm. In addition, part of yokes that are not the main magnetic circuit can be extended to gain efficient support against electromagnetic force between poles.

The magnet is equipped with a set of cold diodes to provide a rapid discharge of stored magnetic energy in two coils, in case of current lead failure and also coil quench.

Table 2 Parameters of the Superconducting Magnet

Superconducting wire	
Type	Monolithic, NbTi/Cu
Cu/NbTi ratio	2
Dimensions (insulated)	0.9x1.3mm^2
Magnet	
Number of turns	2549
Operating current	172 A at 4T
Central magnetic field	4 T
Peak field at conductor	6.1 T
Stored magnetic energy	50 kJ
High-field inductance	3.2 H
Magnetomotive force	450 kA

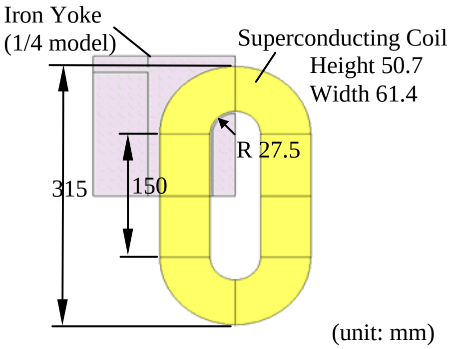

Figure 3: Dimensions of the Superconducting coil

Cryostat Design

Vacuum vessel for cryostat is made from SS304, with sufficient thickness and rib-reinforcement to minimize the deformation effect, caused by vacuum, to the wiggler system alignment. The vacuum vessel has C shape as the same as the cold mass. Upper and lower plates of the vacuum vessel employ flanges, in case of parts replacement for some failure, and also future upgrade capability.

Conduction-cooling with a 2-stage 4K GM cryocooler is employed by the cold mass of the wiggler, this makes the system liquid helium free [3], so the system can be stable and economical. Cold head of the cryocooler is attached mechanically with the cold mass.

To make the replacement of the cold head easy, the front edge of the cold head is inserted precisely in the female-die-shape metal block. The front edge is not bolted or fixed, so it is detachable. It also makes the performance reproducibility of the cold head better through maintenance. This layout is shown in Figure 4.

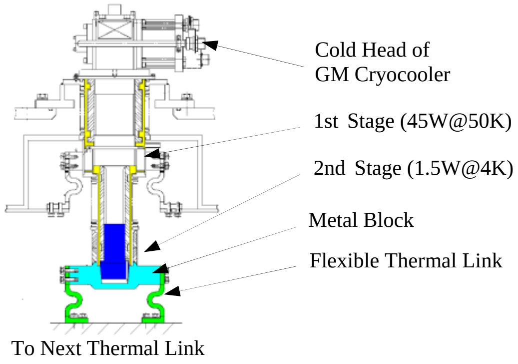

Figure 4: Layout of GM Cryocooler Setting

The metal block contacted to the cold head 2nd stage is linked to flexible thermal links, those are connected to the next thermal link made from annealed copper. Finally it is connected to high-purity copper plates attached to a pair of superconducting coils. These thermal conducting paths also have refrigerant pipes to allow rapid cooling with liquid nitrogen down to about 80K.

HTS current leads are employed between 60K and 4K, to reduce heat load to 4K. Whereas conductively cooled copper alloy current leads are used in the range of temperature 300K to 60K.

The design heat loads are tabulated in Table 3. Sum of 60K heat loads is 29.4W, sum of 4K heat loads is 0.45W.

Table 3 Summary of Design Heat Loads

Source	Heat Load to 60K (W)	Heat Load to 4K (W)
Current Leads	20	0.2
Thermal Radiation	4.8	0.07
Magnet Supports	1.9	0.03
Tubes and Bellows	2.5	0.13
Instrumentation Wires	0.2	0.02
Total	29.4	0.45
Cryocooler Capacity	45 (at 50K)	1.5

Refrigeration capacity of its cryocooler is 45W at 50K and 1.5W at 4K. It is found that the refrigeration capacity has sufficient margin for steady operation.

Cold mass is suspended with 4 CFRP rods from the upper plate of the vacuum vessel. Medium plane of the magnet shifts 0.5mm upward during cooling because of sum of thermal contraction of each part. So the cold mass is preliminarily positioned 0.5mm lower than its normal position when assembling them at room temperature.

Ac Loss

The wiggler is required to increase current during the electron beam acceleration time from 0.26GeV injection energy up to 1.4GeV storage energy. The AC loss in charging or discharging of the superconducting coils causes heat generation inside the coils. It reduces temperature margin of the coils. Adjusting the filament diameter and the filament twist pitch properly, which is incorporated with the conductor's manufacturing cost, achieved AC loss oriented temperature rise dT=0.6K at 0.15A/s. It keeps a sufficient temperature margin.

Magnet excitation generates heat load not only in the coils, but also in the iron yoke. Figure 5 shows time evolution of heat load, which is caused by eddy current, in the iron yoke. In the beginning of charging, relatively large heat load is generated because magnetic flux penetration depth is yet small.

Eddy current is also caused in copper parts for the conduction-cooling configuration. Slits are inserted partially to these copper parts and eddy current is effectively reduced.

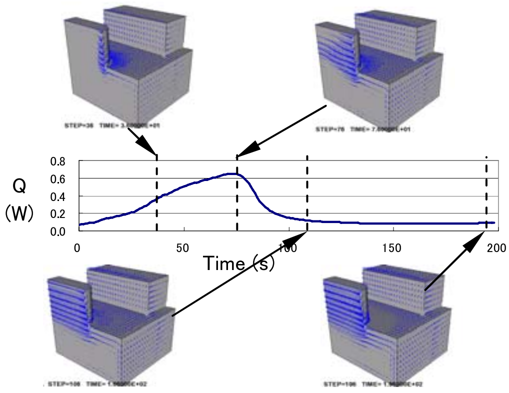

Figure 5: Heat Load by Eddy Current and Magnetic Field Vector in Iron Yoke

MANUFACTURE OF MAGNET

Coil winding process is shown in Figure 6. Conductor with rectangular cross section is advantageous in packing factor and precision of coils.

After the cryostat assembly, superconducting main pole and normal conducting side poles are installed on the integrated movable base. The base has three axis adjustment bolts for each magnet, and linear guide for the wiggler when moving into or pulling out of the beam duct. Figure 7 shows the completion of the superconducting wiggler in the machine shop.

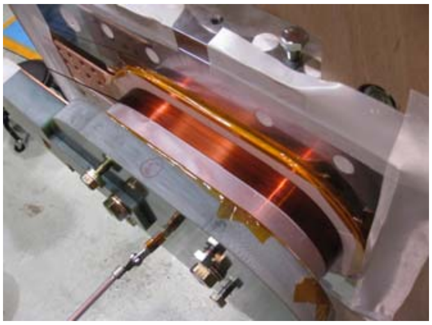

Figure 6: Coil winding process

Figure 7: Completion of the Superconducting Wiggler in the machine shop

CONCLUSION

A 4T superconducting wiggler, which had been planned by SAGA-LS, was designed and manufactured. It is a 3-pole wiggler and comprises one superconducting main pole and two normal conducting side poles. The main pole is cooled with a 2-stage GM cryocooler, which provides steady, reliable and economical liquid-helium-free operation.

The superconducting wiggler is planned to be on commissioning in 2010 summer.

REFERENCES

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