DEVELOPMENT OF SUPERCONDUCTING WIGGLER AT NIRS

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Abstract

A wiggler with three-pole is under development. Coils of the central pole and the auxiliary poles were wound with superconducting wires of Nb_3Sn and NbTi, respectively. Only a cryocooler without liquid helium refrigerates the coils. The various tests such as a cooling test, a quench test and the measurement of a magnetic field were carried out. The field of the central pole achieved about 7 T. The magnetic field distribution was measured with Hall proves along the central line of the beam duct. As the results of these tests, it was found that it is almost according to its design.

1. INTRODUCTION

We have a plan to construct a synchrotron light source dedicated to medical applications at the National Institute of Radiological Sciences (NIRS). The final goal of the plan is to install a compact light source in a hospital in order to use it practically for medical diagnoses or radiotherapy. We proposed the design of a compact light source in ref. [1]. In this system, the 7 T superconducting wiggler with 11 poles is necessary to produce the photon flux of 1.4×10^{13} photons sec^{-1} $mrad^{-1}$ $(0.1\%\ bandwidth)^{-1}$ at 33keV for a coronary angiography, which is considered as a medical diagnosis that requires the most photon flux [2].

The multi-pole superconducting wiggler is one of key-devices to make a synchrotron light source compact. We have, therefore, developed a prototype for the 7 T superconducting wiggler with 11 poles. The prototype is the 7 T superconducting wiggler with 3 poles using a conductive cooling system in which coolant such as liquid helium is not necessary. Here, the prototype wiggler is outlined and results of several tests are reported.

2. STRUCTURE

2.1 Outline

The schematic view of the wiggler is shown in Fig. 1 and its principal parameters are listed in Table 1.

The cryostat is made of stainless steel with a dimension of 840 mm wide × 1184 mm long × 1150 mm high. The inner structure is thermally insulated from the outer wall by a 50 K thermal shield made of copper. The cryostat has a cryocooler on the top. The cryocooler cools a thermal buffer tank with a volume of 3.4 liters through a flexible thermal connector. The wiggler coils are thermally anchored at the thermal buffer tank temperature.

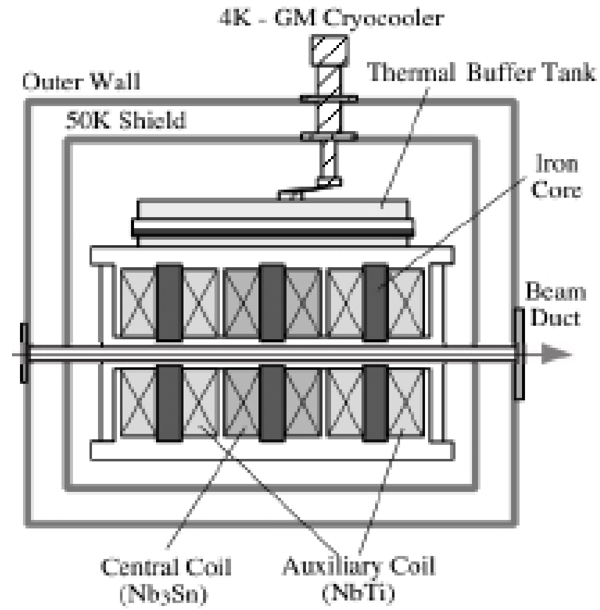

Fig. 1 Schematic view of the prototype wiggler.

Table 1 Principal parameters of prototype wiggler.

Dimension	840(W) × 1184(L) × 1150(H) mm	
Number of poles	Central: 1	Auxiliary: 2
Field of poles	Central: 7 T	Auxiliary: 4 T
Wire of coil	Central: Nb_3Sn	Auxiliary: NbTi
Coil Gap	66 mm	
Period length	420 mm	
Operating current	208 A for 7 T	
Ramp speed	10 A/min	
Cryocooler	4K – GM Type	
	1.3 W at 4.2 K, 40 W at 45 K	
Heat leakage	0.9 W at 4 K	
Average AC loss	0.53 W	

Coils are confined in stainless-steel cases to keep the positions. A beam duct has a tapered shape to keep clearance for emitted radiation from electrons running along the wiggling beam path. Its horizontal aperture is 300 mm at the exit. The aperture for an electron beam has an elliptical shape of 20 mm vertical × 50 mm horizontal. Since the inner surface of the beam duct is at room temperature, the beam duct is surrounded by superinsulation to shield heat radiation. The gap distance between the upper coil and lower coil is 66 mm. HTS (High Temperature Superconductor) current lead of Bi-2223 are used.

2.2 Coils

The peak magnetic field at the central pole is 7 T and the return field at the auxiliary poles is –4 T. Then, the central coils produce the magnetic field of 9.5 T. Nb_3Sn is the best choice for the central coil to operate at a suitable ratio of the operating current to the critical current. The coils of the auxiliary poles were wound with wires of NbTi.

Since each coil have a racetrack shape to give a compact wiggler design, it receives a large electromagnetic stress; the central coils receive a stress of 175 MPa at the corners and of 40 MPa at the straight sections. In order to stand for the stresses, the alumina-Cu reinforced Nb_3Sn wire was developed by *Toshiba Corporation* and *Furukawa Electric Co., Ltd.* [2]. The wire's tensile stress is as twice as that of the conventional Nb_3Sn wire.

In addition, iron cores are inserted in all racetrack-shaped coils and are connected to a back yoke, so that the magnetic field is increased by about 10%.

2.3 Cooling System

The coils are conductively cooled by a GM cryocooler whose 4 K stage is equipped with a buffer tank that can be used as a reservoir for a coolant. It was originally designed that liquid helium of 0.5 liters was stored in the buffer tank in order to compensate for AC loss in charging or discharging of the coils. However, the AC loss is absorbed enough only by the heat capacity of the buffer tank without liquid helium. Only the cryocooler of 1.3 W at 4.2 K is keeping the temperature of the coils as low as around 5 K.

With the aid of coolants of liquid nitrogen and liquid helium, it took about 250 hours to refrigerate the system from the room temperature using the cryocooler. It is estimated that it takes about 1000 hours to refrigerate the system using the cryocooler without any coolant.

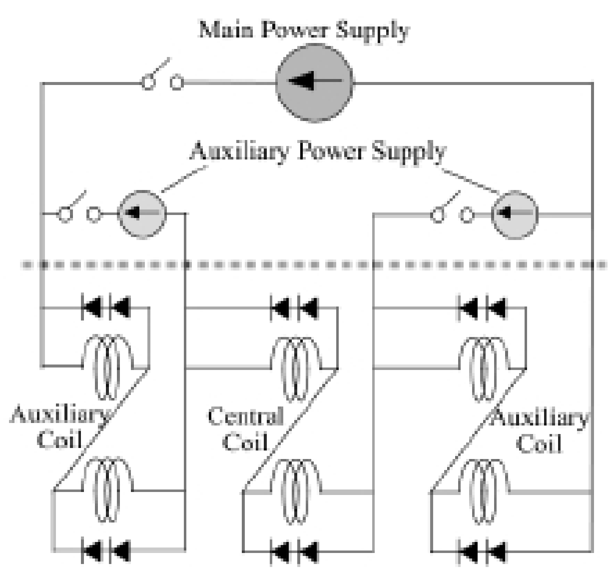

Fig. 2 Circuits of the prototype wiggler.

2.4 Circuits

The circuits of coils are shown in Fig. 2. All coils are connected in series to the main power supply. In addition, the auxiliary power supplies are connected to both auxiliary coils in order to correct a dipole field integral independently. Diodes are connected to each coil in parallel, to protect the coil by bypassing a current in a quench.

The coil voltages and the current lead voltages are always monitored. The coil voltage more than 3 V or the current lead voltage more than 2 mV, which could indicate a quench in the coil or in the current lead, causes the main power supply to turn off automatically.

3. TESTS AND RESULTS

3.1 Excitation and De-excitation Test

We expected that the coils were repeatedly charged to 208 A and discharged to 0 A in a rate of 10 A/min in the typical operation. In order to make certain that the practical operation of the wiggler in the synchrotron, the excitation and de-excitation test was carried out. The results are shown in Fig. 3.

The coil voltages behaved in a non-linear manner at the charged current lower than 10 A and became a constant value of 1.2 V at the current more than 10 A in which the magnetization of iron-core was saturated. The voltage is larger than the one anticipated from a coil inductance of

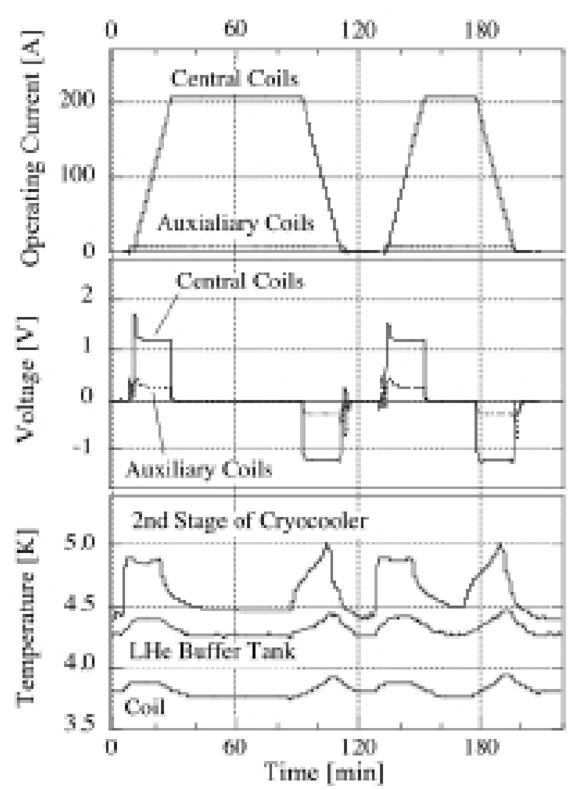

Fig. 3 Coil voltages and temperatures at some points for Current operation.

5.4 H due to a mutual inductance.

No flux-jump was observed while the magnetic field was being ramped. From this fact, it is found that the coil works stably even in the high magnetic field. The temperature of coils did not rise over the designed value of 5 K while the coils were being charged or discharged.

3.2 Measurements of Field Distribution

In the measurement of the magnetic field distribution, a long support tube was installed along the axis in the beam duct and a rod, of which a Hall probe (*HTR99-0618* by *the Bell Co., Ltd.*) was fixed at the tip, was moved in the tube by a stepping motor. Since the Hall probe had temperature stability of ±0.13 Gauss/˚C, the measurement were carried out in a room adjusted the temperature. The magnetic field was measured in a step of 2.5 mm. The result is shown in Fig. 4 together with calculated values.

The peak field of 6.93 T was obtain by the current of 204.5 A. This current was determined by calculation for producing a peak field of 7 T in the 7 T wiggler with 11 poles. Besides the currents of 9.17 A and 8.93 A were additionally applied on the coil pairs of auxiliary poles of the entrance side and the exit side, respectively. As shown in Fig. 4, the calculated values are good agreements with the measured ones.

Since a return yoke is not used to give a compact wiggler design, the magnetic field extends over a wide range from the wiggler. At a position 1 m away from the edge of the cryostat on axis, the magnetic field was about 1 Gauss. The dipole field integral was 0.01 T·m derived from integrating the field distribution measured in the range from –1360 mm to +1360 mm in the coordinate in which the central peak was taken as the origin.

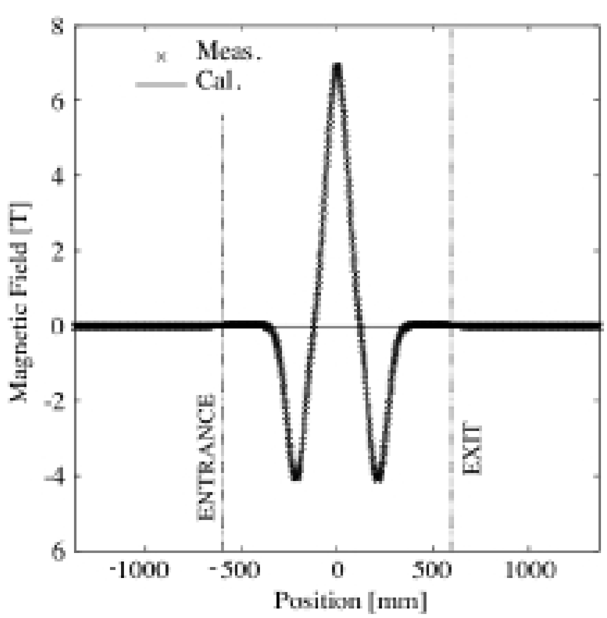

Fig. 4 Magnetic field distribution of the prototype wiggler.

4. SUMMARY

According to these test results, the design specifications have been ensured to be almost satisfied. The cooling system stably works to cool all the coils and keep them at 5 K even lower. The results of magnetic field measurements are in good agreement with its design. We are planning tests to adjust the dipole field integral less than the order of 10^{-3} T·m.

5. REFERENCES

[1] M. Torikoshi, *et al.*, J. Synchrotron Rad. 5 (1998), p.336

[2] T. Kurusu, *et al.*, Proc. of the 12^{th} Symp. On Acc. Sci. and Tech., 1999, Wako, p.331