Development of 7T Superconducting Wiggler Magnet
- Manufacture of Reinforced Nb3Sn Coil and Experiment with a Cooling Structure -

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Abstract

A 7T nine-pole wiggler is a key component of the compact synchrotron light source which National Institute of Radiological Sciences (NIRS) is planning. In order to develop the compact wiggler, the authors have developed an alumina-Cu reinforced Nb3Sn coil whose tensile strength tolerance is almost double that of conventional Nb3Sn coils, and a cooling structure which could reduce refrigerator power to half that required for conventional cryocooler magnets. In the present paper, we introduce the design a manufactured coil and report experimental results respecting the cooling structure.

1 Introduction

NIRS proposes a compact system for medical diagnosis using synchrotron orbital radiation, intravenous coronary angiography, monochromatic X-ray computer tomography and so on [1][2][3]. Toshiba is collaborating with NIRS on blueprinting of the system and developing devices for it [4]. A key component of the system is a superconducting multipole wiggler with nine poles and a maximum field of 7T. Fig. 1 shows a schematic view of the wiggler. It is compact and a new cooling structure, in which GM refrigerators cool a liquid helium buffer and then the buffer cools superconducting coils by heat conduction, is to be adopted for the wiggler. A schematic diagram of the structure is shown in Fig. 2. As shown in the diagram, compared with a conventional cryocooler cooled type, the cooling structure has an advantage in terms of power saving refrigerator because latent heat of helium is available for AC loss of coils. In addition, the coil gap can be shortened because the proposed structure is simpler than that of a conventional helium bath filled type.

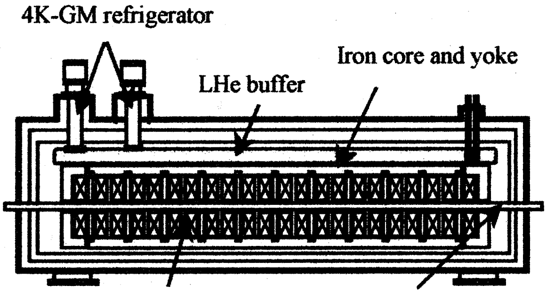

Fig. 1 Schematic view of the 7T nine-pole wiggler (a cross section through the vertical plane along the magnet axis)

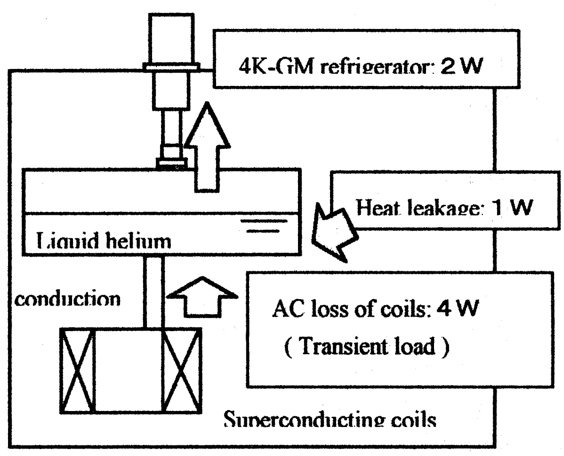

Fig. 2 Schematic diagram of a new cooling structure of 7T nine-pole wiggler.

In order to develop the compact 7T nine-pole wiggler, the authors developed an alumina-Cu reinforced Nb3Sn coil whose tensile strength tolerance is almost double that of conventional Nb3Sn coils, and then performed an experiment respecting the cooling structure.

2 Coil Design

2.1 Reinforced Nb3Sn Coil

Since a wide beam chamber is required for the 7T nine-pole wiggler, a coil gap is designed in consideration of a support structure, besides Nb3Sn is adopted as a superconductor in order to give a compact wiggler design.

The superconducting coils of the wiggler are required to have high mechanical strength, since a result of our preliminary study indicates that a transient stress would be too severe for conventional Nb3Sn coils to withstand if the coils were quenched.

Therefore, the authors developed a Nb3Sn wire reinforced by alumina-Cu in corporation with The Furukawa Electric Co., Ltd. The wire's tensile stress at 0.3% strain is 270MPa, a strength almost double that of conventional Nb3Sn wire. The specification of the wire is given in Table 1.

The manufactured coil has a racetrack shape. Its winding is graded into two sections and impregnated by an epoxy. The specifications of the coil and the wiggler are given in Table 2 and Table 3, respectively.

Table 1 Specification of reinforced Nb3Sn wire

	G1-type	G2-type
Superconductor	(Nb,Ti)3Sn	
Size Thickness	1.15mm	0.8mm
Width	1.68mm	1.25mm
Filament number	19,000	
Matrix ratio	1.0	
Matrix	Alumina-Cu, OFC	
Critical current at 12T (0.1 μ V/cm,4.2K)	430A	240A

Table 2 Specification of the reinforced Nb3Sn coil

Inner radius at round portion	28mm
Outer radius at round portion	96mm
Length of straight portion	150mm
Width	195mm
Height	157mm
Rated current	208A
Maximum field	9.5T
Inductance	5.4H/coil

Table 3 Specification of the 7T nine-pole wiggler

Designed field on beam line	7.0T
Period length	210mm
Coil gap	66mm
Field integral ∫B dz	< 1mTm
Relative field error	< 0.5%
Beam stay clear aperture vertical	±5mm
horizontal	±10mm

We are currently preparing an experiment to demonstrate the coil's performances. We are also preparing fabrication of the 7T three-pole wiggler as a prototype of a nine-pole wiggler using the coil.

2.2 AC loss and Quench Simulation

AC loss

AC loss of the coil, charged up to 7T for 20 minutes, is estimated by a model [5][6]. The result is shown in Fig. 3. In the model calculation, the critical current density; Jc [A/m^2], of Nb3Sn is approximated by the following equation whose coefficients are determined to fit the actual measurement.

$$Jc(B)=5.7\times10^{9}(B^{-0.5}-7.5\times10^{-2}B^{0.5}+1.4\times10^{-3}B^{1.5}) \quad (1)$$

Here B represents magnetic field in Tesla. As shown in the figure, there is a rapid drop at the beginning and it is found that the loss at the end is almost a third of mean value.

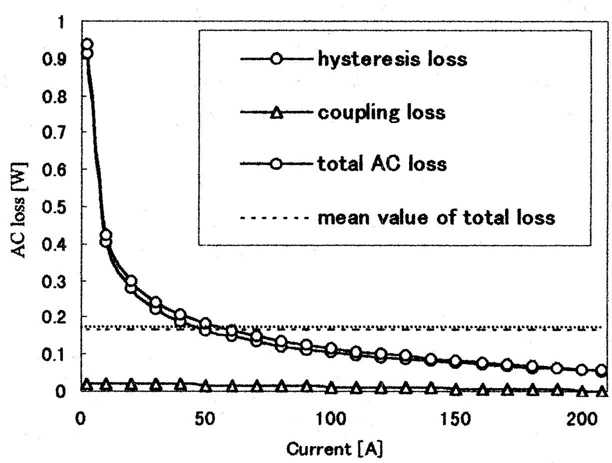

Fig. 3 Estimated AC loss of the reinforced Nb3Sn coil

Quench Simulation

In order to investigate behavior of coil quenching, a numerical analysis of quench in the 7T nine-pole wiggler has been carried out. The results are shown in Fig. 4. The figure shows transition of coil current when a CoilA_upper is quenched. Here CoilA_upper represents the upper coil of the center pole and it consists of a pole with CoilA_lower. CoilB_upper/lower is the next pole to CoilA_upper/lower and CoilC_upper/lower is the next pole to CoilB_upper/lower. As shown in the figure, it is estimated that only the coil opposite the quenched coil, CoilA_lower, would be quenched by magnetic induction. Then the maximum temperature of the quenched coil is estimated to be about 95K. Moreover, employing the time constant of current decay for the post-analysis, the internal voltage inside the quenched coil is estimated to be about 1.8kV.

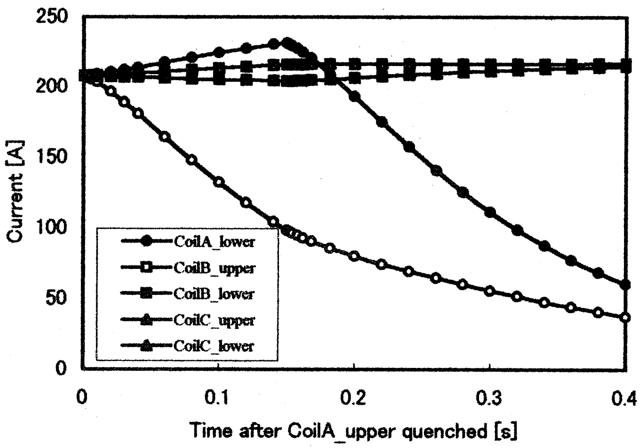

Fig. 4 Transition of coil current when CoilA_upper quenched.

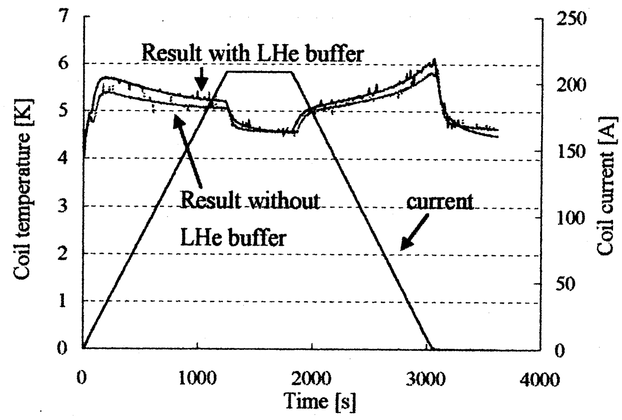

Fig. 6 Transition of coil temperature during charge of the coil

3 Cooling Structure

Fig. 5 shows the experimental apparatus which was prepared in order to demonstrate the cooling structure and obtain data. The experiment was carried out using a Nb3Sn coil whose shape is as same as that of the reinforced coil. The experimental result is shown in Fig. 6. The figure shows that temperature rise of the coil is suppressed by LHe buffer when the coil is charged or discharged. In other words, the effect of the power saving respecting the refrigerator has been confirmed.

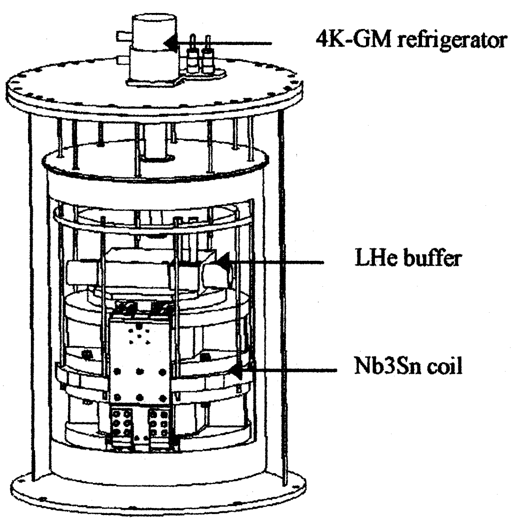

Fig.5 Experimental apparatus

5 Summary

We have developed an alumina-Cu reinforced Nb3Sn coil and examined a new cooling structure in order to develop a 7T nine-pole wiggler. Details will be presented at the conference.

Acknowledgement

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