Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 67 (2015) 326 – 330

Physics Procedia

25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014

Concept of a cryogenic system for a cryogen-free 25 T superconducting magnet

Sadanori Iwai[a]*, Masahiko Takahashi[a], Hiroshi Miyazaki[a], Taizo Tosaka[a], Kenji Tasaki[a], Satoshi Hanai[a], Shigeru Ioka[a], Kazuo Watanabe[b], Satoshi Awaji[b], Hidetoshi Oguro[b]

[a] *Toshiba Corporation, Yokohama 230-0045, Japan*

[b] *High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan*

Abstract

A cryogen-free 25 T superconducting magnet using a ReBCO insert coil that generates 11.5 T in a 14 T background field of outer low-temperature superconducting (LTS) coils is currently under development. The AC loss of the insert coil during field ramping is approximately 8.8 W, which is difficult to dissipate at the operating temperature of the LTS coils (4 K). However, since a ReBCO coil can operate at a temperature above 4 K, the ReBCO insert coil is cooled to about 10 K by two GM cryocoolers, and the LTS coils are independently cooled by two GM/JT cryocoolers. Two GM cryocoolers cool a circulating helium gas through heat exchangers, and the gas is transported over a long distance to the cold stage located on the ReBCO insert coil, in order to protect the cryocoolers from the leakage field of high magnetic fields. The temperature difference of the 2nd cold stage of the GM cryocoolers and the insert coil can be reduced by increasing the gas flow rate. However, at the same time, the heat loss of the heat exchangers increases, and the temperature of the second cold stage is raised. Therefore, the gas flow rate is optimized to minimize the operating temperature of the ReBCO insert coil by using a flow controller and a bypass circuit connected to a buffer tank.

Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014

Keywords: cryogen-free; ReBCO; GM; circulating; gas flow

* Corresponding author. Tel.: +81-45-510-6695; fax: +81-45-500-1427.
E-mail address: sadanori.iwai@toshiba.co.jp

Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014
doi:10.1016/j.phpro.2015.06.095

1. Introduction

The generation of high magnetic fields is important in research for deriving a variety of new physical properties. Recently, there has been an increasing need for high-field magnets [1-5] for materials research. The critical current density of ReBCO coated conductors has shown remarkable improvements in recent years, and their mechanical strength is also high, allowing the generation of high magnetic fields of more than 20 T [3-5], which is difficult to achieve with NbTi and Nb_3Sn conductors alone. Moreover, ReBCO-coated conductors can operate for practical use at 10–40 K. This means that a coil wound with a ReBCO-coated conductor is suitable for operation using a conduction cooling system, which does not need liquid helium.

A new 25 T cryogen-free magnet using a ReBCO insert coil in the inner coil of outer low-temperature superconducting (LTS) coils wound with NbTi and Nb_3Sn is currently under development at Tohoku University [6]. Until now, 18 T cryogen-free magnets, and an upgraded magnet generating 20 T, both having Bi2223 insert coils, have been developed at Tohoku University [7,8]. Compared with the 20 T cryogen-free magnet, in a 25 T cryogen-free magnet, the magnetic field contribution of the insert coil will be 2.5 times higher, and the total conductor length will increase drastically. As a result, the AC loss of the ReBCO insert coil during the specified field ramping time of 60 min will produce a heat load of approximately 8.8 W. Meanwhile, to provide protection from the leakage field of high magnetic fields, the cryocoolers must be arranged at positions away from the coils, so that a long-distance cooling technique is required.

In this paper, we discuss the concept of a cryogenic system for a 25 T cryogen-free magnet, in which the cooling systems of the LTS coils and the ReBCO coil are separated. They are independently cooled to different operating temperatures of 4 K and 10 K.

2. Concept of the cryogenic system

The specifications of the 25 T cryogen-free magnet are shown in Table 1. The magnet uses a ReBCO insert coil that generates 11.5 T in a 14 T background field of outer LTS coils [6]. In the case of the previous 20 T conduction cooling magnet, both the LTS and HTS coils were cooled by a single GM/JT cryocooler with a 4.3 W-class cooling capacity at 4.2 K. In the 25 T conduction cooling magnet, the heat load of the LTS coil cooling system is currently estimated to be about 5.5 W, and if we add this to the ac-loss of the ReBCO insert coil (8.8 W), the total will be 14.3 W. To dissipate this heat load with 4.2 W-class GM/JT cryocoolers with a cooling capacity of 4.3 K [9], at least four sets will be required, and complicated pipe lines must be arranged in a limited space. However, a ReBCO coil has a high critical current density in practical use at 10–40 K, and it does not necessarily need to be cooled at 4 K. In a temperature range of about 10–40 K, a GM cryocooler has a higher cooling capacity of 10 W at 8 K (1.5 W at 4.2 K) [10] than that of a GM/JT cryocooler at 4 K and is cheaper. Thus, the cooling systems of the LTS coils and the cooling system of the ReBCO coil were separated, and the coils were independently cooled to different operating temperatures of 4 K and 10 K.

For long-distance cooling, the LTS coils were cooled by GM/JT cryocoolers in which a cooling pipe is extended to the LTS coils, based on the design of the cooling system for the previously developed 18 T and 20 T cryogen-free magnets. On the other hand, the ReBCO coil was cooled by circulating helium gas by using GM cryocoolers and a helium compressor. In both cases, the temperature difference of the heat transfer is independent of the distance over which the helium mist and gas circulate. By optimizing the gas flow rate, the temperature of the cold stage of the coil was minimized to 8.5 K when operating at 0.5 g/s, even when a heat load of about 10 W was generated.

Table 1. Specifications of the 25 T cryogen-free magnet.

Parameter	HTS	LTS1	LTS 2	LTS 3	LTS 4	LTS5
Conductor	ReBCO	Nb_3Sn	Nb_3Sn	Nb_3Sn	NbTi	NbTi
Inner diameter (mm)	102	300	372	458	545	628
Outer diameter (mm)	276	366	452	539	622	712
Coil height (mm)	408	540	628	628	628	628
Magnetic field contribution (T)	11.5	2.43	2.91	2.73	2.69	3.24