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전도 냉각형 10kJ 고온 초전도 에너지 저장장치의 열 부하 특성 해석

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Heat load characteristic analysis of conduction cooled 10kJ HTS SMES

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Abstract - The characteristics of the Superconducting Magnetic Energy Storage (SMES) system are faster response, longer life time, more economical, and environment friendly than other Uninterruptible Power Supply (UPS) using battery. Fast charge and discharge time of SMES system can provide powerful performance of improving power quality in the grid. In order to demonstrate the effectiveness of SMES, the authors make a 10kJ SMES system for connection with RTDS (Real Time Digital Simulator). Because the characteristics of superconducting magnet are very important in SMES system, the necessary items such as thermal characteristic, mechanical stress and protection circuit should be considered. In this paper, the authors experimented thermal characteristics of the 10kJ SMES system. The experiment was accomplished using a simulation coils made of aluminium. It has same dimension of the 10kJ class HTS SMES coil. The coil was cooled with GM (Gifford -McMahon) cryocooler through the OFHC (Oxgen Free High thermal Conductivity) conduction bar. The test results of cool down and heat loads characteristics of the simulation coils are described in detail.

1. Introduction

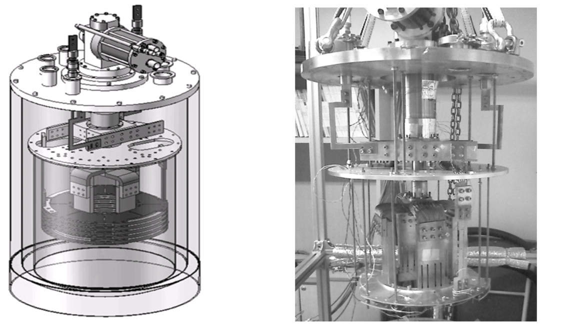
SMES system is an outstanding power compensator because of its fast response time with high energy storage efficiency. Especially, HTS (High Temperature Superconductor) SMES system which is more efficient than usual storage device using low temperature superconducting devices and has small installation area has been developing in world wide [1]. To demonstrate the effectiveness of SMES system, the authors have been studying for the system application and manufacturing a 10kJ class HTS SMES system under conduction cooling condition.

The HTS SMES system needs an cryogenic cooling to maintain its superconductivity. There are two ways in cooling system, one is the liquid cooling system and the other is the conduction cooling system. The liquid cooling system deposites objects in liquid nitrogen, neon or helium and cools it. On the other hand, the conduction cooling system connects object to cryocooler directly or indirectly in a vacuum chamber. It does not need regular replacement of refrigerant compared with the liquid cooling system and the users can prevent the several accident caused by liquid cooling. And the users can get the cryogenic condition easily when they only turned on the power switch after system organization [2], [3].

2. Conduction cooling system

2.1 Design of conduction cooling system

Fig. 1 shows the deigned and manufactured conduction cooling system for the 10kJ SMES system. The cooling machine is GM cryocooler which has two stage conduction head. The 1st stage cold head cools the current leads which are connected with room temperature condition, conduction pad which is connected between current lead and HTS current lead, and super insulation which can prevent a radiation heat from outside. The 2nd stage cold head cools the HTS magnet using two flexible copper braids and four conduction bars.



(a) (b)

<Fig. 1> Conduction cooling system (a)Designed 10kJ SMES system (b) Manufactured conduction cooling system

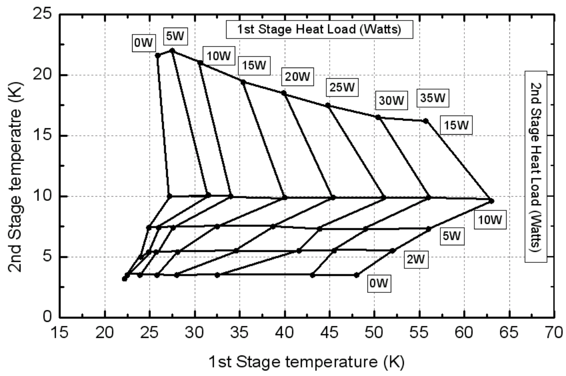
2.2 The prevent of heat invasion

The protection from heat invasion is very important in cryogenic system. Generally, thermal conductivity is increased and specific heat is decreased by temperature decreasing. So temperature of the SMES system which is operated under cryogenic temperature influenced a lot by even extremely small heat invasion. The cryostat of the 10kJ SMES system has vacuum condition. So there is no conduction and convection from outside to SMES system. Also there is an insulation film called super-insulation for radiation [4].

3. Experiments and results

3.1 Experiment of cryocooler performance

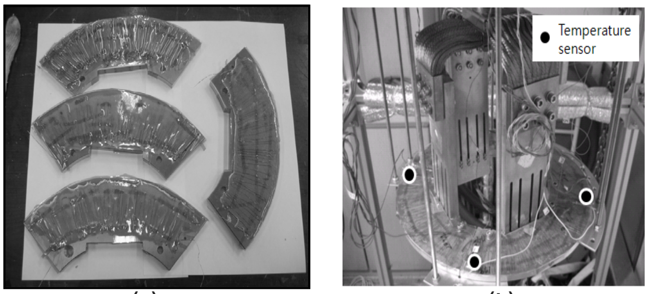
GM cryocooler consists of two stages cold head was used for the 10kJ SMES system. First stage cools down copper current lead and radiation shield. Second stage cools down the conduction bar, HTS current lead, and superconducting wire which needs lowest temperature in SMES system. Fig. 2 shows the experiment results of the cryocooler performance. The temperatures of each stage were measured under various heat load conditions.



<Fig. 2> Temperature characteristics of GM cryocooler according to various heat loads

3.2 Experiment of cooling characteristics

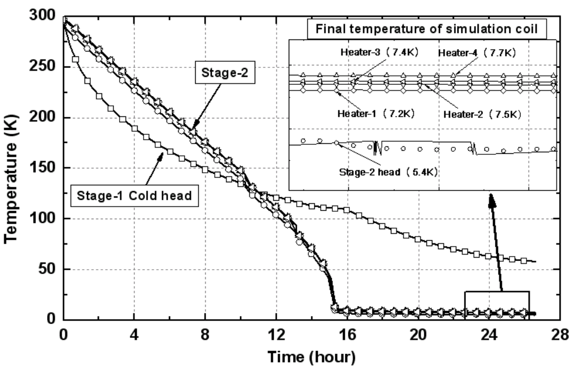
The temperature variation of the 10kJ SMES system was experimented by losses during charge or discharge. The simulation coil which has the same dimension was designed for the heat load experiment. Heat generated by Nichrome wires. Fig. 3 shows the manufactured simulation coil and conduction cooling system. Nichrome wires were attached to the surface of the simulation coil using epoxy. Between Nichrome wire and simulation coil, Kaptone tapes were used for insulation to protect the cryocooler. Four sensors were used in the simulation coil. Also the cold head of 1st and 2nd stage temperatures were measured. For temperature measurement, DT-670 silicon diode sensors made by Lakeshore were used.



(a) (b)

<Fig. 3> Experimental set up (a)Simulation coils (b)Position of sensors

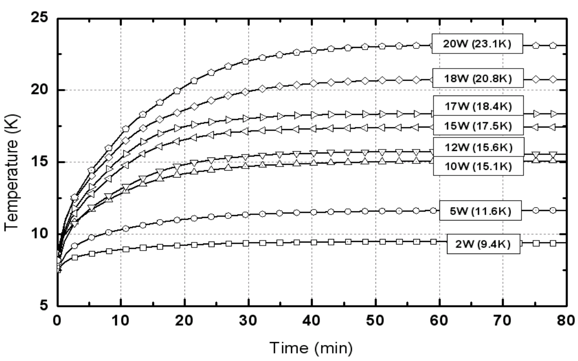
Fig. 4 shows the experiment results of the cooling time from room temperature to cryogenic temperature. 25 hours needed to complete the cooling. The final temperatures of 1st stage and 2nd stage were 5.3K and 7.4K.



<Fig. 4> Temperature variation of the conduction cooling system

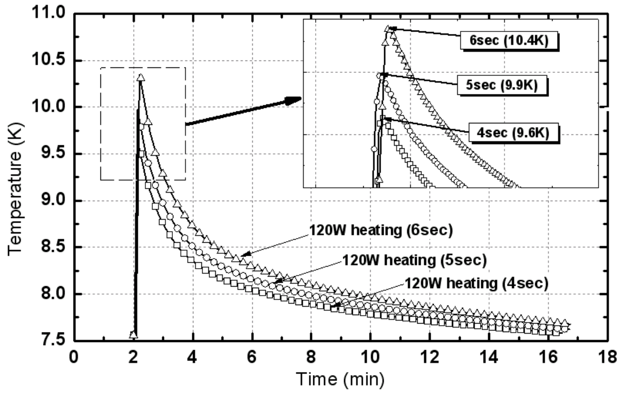
3.3 Experiment of heat load characteristics

To predict the SMES coil temperature during charge or discharge, simulation coil heated as the same condition of SMES coil. Fig. 5 shows temperature variations of the SMES under standby status. The copper current leads generated the heat by its electrical resistance.



<Fig. 5> Temperature variations from 2W to 20W

In case of the standby status of the SMES, the rated current generates the heat. Fig. 5 shows the experiment results of temperature increasing by continuous heating. Operating temperature of the designed system is under 20K. The experiment results shows that the system temperature was increased to 20K from 18W heat load. Fig. 6 shows the temperature variation during charge or discharge. The 10kJ SMES system losses during charge or discharge is 360J. The 120W of heat injected using Nichrome wire for 3 seconds. The heat energy of Nichrome wire would not propagate to simulation coil directly, so the experiment time took for 4, 5 and 6 seconds, respectively.



<Fig. 6> Temperature variations due to the charging or discharging currents

4. Conclusions

The temperature characteristics of the 10kJ SMES are described in this paper. The performance of conduction cooling system was experimented using simulation coil. Temperature gab between cryocooler and simulation coil was 2.2K. This temperature gab will be reduced by thermal conductivity of connection between cryocooler and HTS magnet. The designed operating temperature of the system is under 20K. Manufactured conduction cooling system can cool down to 20K under 17W heat generation. More than 17W heat, the system could not operate under 20K. We expected that the performance of the designed conduction system had no problems during charge or discharge. Maximum increasing temperature of the SMES system is 10K during charge or discharge.

The cooling time from room temperature to 20K was much longer than we expected. The connection parts caused the thermal conductivity problem. The performance of the conduction cooling system could be increased by the improvement of connection method of each part and they be further study tasks.

Acknowledgement

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