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N. KIMURA, Y. AJIMA, Y. DOI, T. HARUYAMA, N. HIGASHI, M. IIDA, S. KATO,
M. KAWAI, H. KAWAMATA, S.W. KIM, Y. KONDOU, Y. MAKIDA, K. MIMORI,
S. MIZUMAKI, T. NAKAMOTO, T. OGITSU, H. OHHATA, N. OHUCHI, S. SUGAWARA,
T. SHINTOMI, K. TANAKA, A. TERASHIMA, K. TSUCHIYA,
H. YAMAOKA and A. YAMAMOTO

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Cooling Performance of a Pressurized HeII Cryogenics System for the Superconducting Magnet Test Facility at KEK

Nobuhiro Kimura, Yasuo Ajima, Yoshikuni Doi, Tomiyoshi Haruyama, Norio Higashi, Masahide Iida, Shuichi Kato *, Masanori Kawai, Hiroshi Kawamata, Seog-whan Kim, Yoshinari Kondou, Yasuhiro Makida, Katsuhiko Mimori, Shoichi Mizumaki **, Tatsushi Nakamoto, Toru Ogitsu, Hirokatsu Ohhata, Norihito Ohuchi, Shigekatsu Sugawara, Takakazu Shintomi, Ken-ichi Tanaka, Akio Terashima, Kiyosumi Tsuchiya, Hiroshi Yamaoka, and Akira Yamamoto

National Laboratory for High Energy Physics (KEK), 1-1 Oho, Tsukuba, Ibaraki 305, Japan

* Kyushu University, Fukuoka, 812, Japan

** The Graduate University for Advanced Studies, 1-1 Oho, Tsukuba, Ibaraki 305, Japan

This paper describes a new cryogenic test facility developed at KEK for research and development on high field superconducting magnets. It consists of a vertical double-bath cryostat for 1m model magnets in superfluid helium at atmospheric pressure associated with a vacuum pumping system and a refrigerator/liquefier. The system has been successfully operated since 1995 with a refrigeration power of 8 W at 1.9 K, and two superconducting magnets have been tested.

INTRODUCTION

A cooperative effort to develop high field superconducting magnets has been carried out between CERN & KEK, as part of the joint research program towards the Large Hadron Collider to be built at CERN. A series of high field superconducting model magnets are being developed at KEK[1,2,3].

To test those magnets, a new 1.8 K test facility has been developed at KEK, and a cooling performance test has been carried out by using a dipole model magnet. This paper describes the results of the performance test, of the 1.8 K test facility.

TEST FACILITY

A flow diagram of the test facilities cryogenics system is shown in Figure 1. The cryogenics system consists of a refrigerator/liquefier, a valve connection box, a vertical double bath cryostat with a heat exchanger and a pumping system (1.8 K refrigerator) which provides saturated superfluid helium inside the heat exchanger. The refrigerator/liquefier was built by Teisan/L'Air Liquide and was previously used for the superconducting solenoid in the AMY detector system at TRISTAN[4]. Its cooling power is 300 W at 4.4 K or its liquid helium production capacity is 100 L/h. During cool down of the magnet, it works as a refrigerator. In steady state, it works as a liquefier. Major parameters of the cryogenics system are listed in Table 1.

Table 1. Parameters of the cryogenics system

Cold box	100 L/h (300W at 4.4 K) with LN2
Liquid He Dewar	2500 Liters + 2000 Liters
Liquid Nitrogen Tank	9700 Liters
1.8 K Heat Exchanger area	0.75 m ²
Vacuum Pumping	900 m ³ /h at 13 kPa (Roots pump) + 360 m ³ /h (Rotary pump)
He gas recovery	100 m ³ /h (Recovery compressor) + 20 m ³ (Gas bag)

Figure 1 Flow diagram of the cryogenics system for testing superconducting magnets.

The cryogenics system is controlled by a distributed process control system with modified automatic control programs converted from the AMY superconducting solenoid control system[4]. The cryostat for the model magnet is 800 mm in diameter, 2670 mm in depth, with a GFRP insulating plate between 1.8 K and 4.2 K helium baths as shown in Figures 2 (a) and (b). Liquid helium capacity in each bath is 450 L for 1.8 K bath and 130 L for 4.2 K bath, respectively. A heat exchanger with a J-T valve is equipped in the 1.8 K bath. The pumping system consists of a 900 m³/h roots pump linked with a 390 m³/h rotary pump. The superconducting model magnet with a cold mass weight of about 2.5 tons which was suspended from the insulating plate was immersed in the 1.8 K pressurized super fluid helium bath. The cryostat is equipped with two thermal screens cooled with cold helium vapor gas and a two stages G-M type cryocooler.

Figure 2. (a) A schematic diagram of the cryostat
(b) a photograph of a set up of the magnet with the heat exchanger and GFRP insulating plate.

The power supply for the magnet test has a capacity of 15 kA with 15 V and a stability of 10^{-4} . The monitoring system provides 96 channels with sampling frequencies of 0.1 to 1 Hz for monitoring cool down or warm up of the magnet.

PERFORMANCE TEST AND RESULTS

The cryogenics performance of the 1.8 K test facility has been carried out during a test period of a dipole magnet. For precise measurement of the cooling characteristics and the refrigeration power five carbon glass resistance thermometers were installed in the cryostat as indicated in Fig. 2. The five thermometers are positioned in the cryostat at the: inlet of the 1.8 K refrigerator (T_8), after the pre-cooler (T_{exo}), at the outlet of the J-T valve (T_{exb}), at the surface of the heat exchanger (T_1), and in the 1.8 K pressurized helium bath (T_2).

The cooling process follows two cooling schemes. In the temperature range 300 K - 80 K, the magnet was cooled down using cold helium gas at about 50 K lower than the magnet temperature to eliminate excessive thermal stresses. Helium mass flow rate and gas temperature were automatically controlled to keep the temperature difference within 30 K between the He gas-inlet and the magnet temperature. Below 80 K where the thermal shrinkage becomes negligible, it was cooled quickly to liquid helium temperature by using the liquid helium which was fed to the cryostat from a 2500 L dewar via the valve connection box. After magnet training at 4.2 K, the magnet was cooled down to 1.8 K by flowing helium through the 1.8 K heat exchanger at low pressure.

Figure 3 shows the typical cool-down curve of the magnet from 300 K to 4.2 K, and from 4.2 K to 1.8 K. By using this cryogenics system, the cool-down time of the model magnet from 300 K to 4.2 K took 2~3 days, and the cool-down time from 4.2 K to 1.8 K took 6 hours.

Figure 3 Cool-down characteristics of the model magnet from 300 K to 4.2 K, and from 4.2 K to 1.8 K.

The refrigeration characteristics of the 1.8 K refrigerator were measured as a function of temperature by changing the electrical heater power. Figure 4 shows the refrigeration characteristics of the 1.8 K refrigerator as a function of temperature. A solid line in Fig. 4 represents the theoretical prediction for the ideal refrigeration power given by

$$Q = \lambda \cdot \rho \cdot \dot{m} \quad (1)$$

where λ is the latent heat of the liquid helium, ρ is the density of the helium gas, and $\dot{m}$ is the mass flow rate of the pumping system. In this figure, the lowest obtained temperature of the cryostat was 1.73 K with no heater load, and the refrigeration power of 8 W was obtained at 1.9 K.

With this capacity, five training cycle of the magnet have been performed within 10 hours, with a temperature profile as shown in Fig. 5.

Figure 4 Measured refrigeration power at the superfluid helium region.

Figure 5 The performance of Cooling cycle after quench.

SUMMARY

A cryogenics system for a 1.8 K test facility, for testing high field superconducting magnets at KEK was constructed and tested. A magnet was attached to the vertical double bath cryostat and was cooled down by the refrigeration/liquefier with the automatic computer control system. The cryostat has 8 W of refrigeration power at 1.9 K and it took 6 hours to cool down from 4.2 K to 1.9 K with 450 L of liquid helium and 2 tons of the model magnet. The system could be recovered within 2 hours after a quench at 1.9 K. The fast recovery to 1.9 K after a magnet quench permits several quenches per day and a maximum of five have been demonstrated.

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