DEVELOPMENT OF A MAGNET WITH HIGH CRITICAL TEMPERATURE SUPERCONDUCTING WIRES*

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Abstract

A solenoid magnet using high Tc superconducting wire was designed and fabricated. After the successful cooling tests, performance was studied by operation with both DC and AC currents. We found the magnet can be operated with 100 A at frequencies higher than 1 Hz. The present results indicate many possible applications. The magnet will be used to generate a mirror field of the ECR ion source at 2.45 GHz.

INTRODUCTION

Since the discovery of high-temperature superconductor (HTS) materials in 1986, many efforts have been performed to apply them to various apparatuses as well as to develop new materials [1]. Recently it has become possible to supply long high-Tc wires in greater than 100 m lengths [2]. Although many prototype devises using HTS wires have been fabricated and evaluated, there are only a few applications in the accelerator fields [3].

We designed and fabricated two solenoid coils with HTS wires and made some preliminary tests to investigate the performance and perspectives of the HTS magnets for future applications. These coils will be used to generate a mirror field of an Electron Cyclotron Resonance (ECR) ion source operating at 2.45 GHz. In this paper, we report the design and performance of the coil system.

HTS COILS

Design

Specifications of the present solenoid coils are summarized in Table 1. Cross sectional view of the magnet is shown in Fig. 1. The ECR ion source consists of two HTS coils, 6 permanent magnet (NEOMAX-44H) bars to generate a sextupole field, a plasma chamber and, a micro-wave guide. A two-stage G-M refrigerator is used to cool the coils. The cooling power is 18 W and 9 W at the first (80K) and the second stage (20 K), respectively. Current leads are made of electric copper and thermal anchors are installed in the middle to connect current leads to the first stage of the refrigerator. In order to reduce power losses HTS tapes are soldered on the leads between the thermal anchors and the HTS coils. Power losses at current leads are estimated to be 10 W and 2 W at the high and low temperature region, respectively. Total heat load is estimated to be 18 W and 3 W at the first and second stage of the refrigerator.

Table1: Parameters of the HTS-magnet

HTS-coils	Superconductor	Bi 2223/ Ag tape Total length 360 m
	No. of turns	292 x 2 coils
	Winding construction	4 pancakes / coil
	Rated current	90 A
	Max. magnetic field in the coil	5.2 kG in parallel to tape 3.6 kG in normal to tape
Cryostat	Cooling method	Conduction cooling by a G-M refrigerator
	Thermal insulation	Vacuum isolation, 80K shield and super-insulation
	Cooling power of the G-M refrigerator	9 W at 20 K, and 18 W at 80K

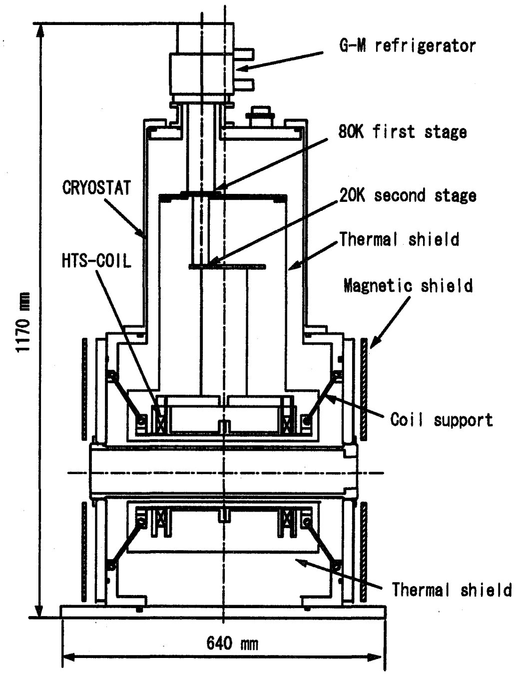

Figure1: Cross sectional view of the HTS solenoid magnet for an ECR ion source.

The HTS wire is a flexible composite consisting of filaments of nominal composition $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ in a silver matrix, which also provides mechanical robustness and transient thermal stability. The tape is 4.2

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*Supported in part by Ministry of Education, Culture, Sports, Science and Technology of Japan.

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mm wide and 0.21 mm thick. The wire (Bi2223) was supplied by Sumitomo Electric Industries, Ltd. Each coil consists of two double-pancakes. The inner and outer diameter of the pancake is 156 and 225 mm, respectively. Each pancake has 146 (73x2) turns and is 9 mm in height. The operating temperature of HTS coils is designed to be 30 K and the maximum current is 90 A.

Performance

The inductance of the pancakes was measured at room temperature and was 6.0 – 6.4 mH which is consistent with the design value of 6.2 mH. The critical current (Ic) of the pancake was measured in liquid nitrogen. Results are 48 – 52 A (1 μV/cm, self-field) for all pancakes. This Ic value is same as that of the tape itself. This shows the wire was not damaged by winding procedure. After stacking two pancakes to make a coil, Ic was again measured in liquid nitrogen to be 36 - 39 A. Same results were obtained after three heat cycles. The achieved performance is better than anticipated and we can expect higher operating current than 90 A at 30 K.

Two coils are mounted on a bobbin made of SUS316. They are connected electrically in series and assembled in a cryostat. Thermal shields are installed and connected to the first stage of the refrigerator. Twenty layers super-insulations are put between the thermal shields and room temperature wall of the cryostat. Figure 2 shows a photograph of the system with thermal shields. The bobbin is supported by four rods of titanium alloy which is 4 mm in diameter. The cryostat is evacuated by a turbo-molecular pump and cooled by the refrigerator. Figure 3 shows the temperature and the ohmic resistance. The HTS coils transited in superconducting state at 105 K with 25 hours cooling time. Coils are cooled down to 13 K, while the equilibrium temperature of thermal shields is about 100 K. Coils are excited with 100 A current without any noticeable rise in temperature. Although we can expect the coil critical current higher than 200A, the operating current was limited up to 100 A because of the thermal capability of the current leads in vacuum. Longitudinal magnetic field distributions are measured along the central axis (z) at 100 A and are shown in Fig.4 together with calculated fields with the program code TOSCA. We can see good agreements between them.

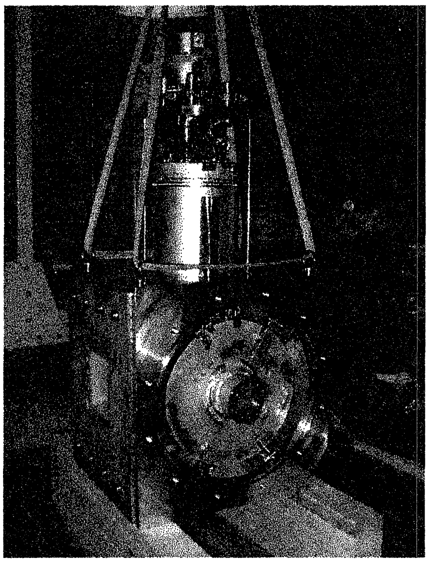

Figure 2: Photograph of the magnet assembled in the cryostat. We can see thermal shields and supporting rods

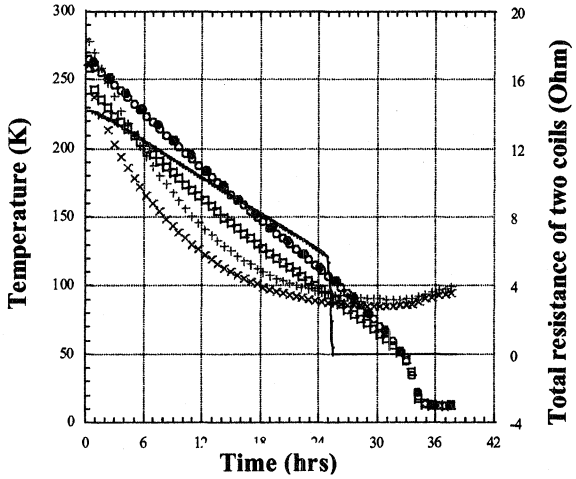

Figure 3: Temperatures and coil resistance on the cooling down with a G-M refrigerator. Circles and squares show temperatures of the coils and the second stage of the refrigerator. Pluses crosses are temperatures of a thermal shield and the first stage of the refrigerator. Solid curve shows the total ohmic resistance of two coils

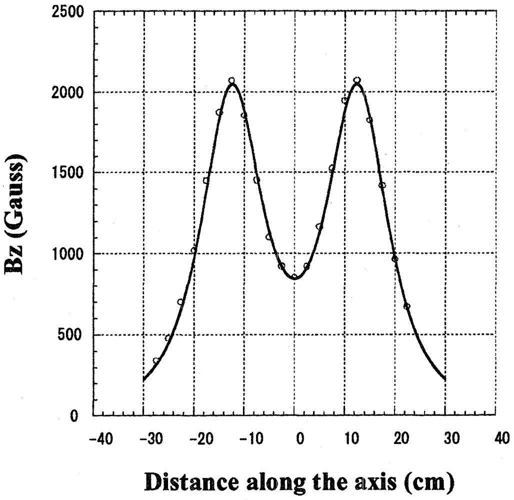

Figure 4: Longitudinal magnetic field Bz distribution along the central axis. The coil current is 100 A.

Owing to the good performance above described, we can expect a large thermal margin for the fabricated coils. This makes it possible to operate the magnet in an AC mode with high frequencies and to keep superconductivity. Figure 5 shows the coil currents measured by a DCCT. The magnet is excited by a homo-pole DC current source at 0.25 Hz. There is a heating load due to the AC loss of superconducting wire. The temperature rise was 2 K after 5 minutes AC operation. At this temperature, the critical current is higher than 100 A. Present results show a large applicability of HTS wires to rapid cycling AC magnets such as scanning magnets for the cancer therapy, high duty synchrotrons, etc.

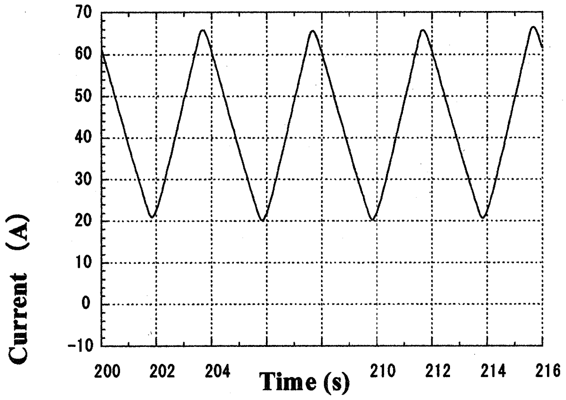

Figure 5: AC excitation pattern with a homo-pole DC current. The frequency is 0.25 Hz. Current is measured at the current lead by a DCCT.

SUMMARY

A solenoid magnet was fabricated with the HTS wire Bi2223. A two-stage G-M refrigerator could cool the system to 13 K and the critical current of the wire is higher than 100 A at 20 K for the present configuration. The magnet can be excited by AC currents at frequencies higher than 0.5 Hz. This shows a large applicability of HTS wires to rapid cycling magnets.

REFERENCES

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