HTS MAGNET TO POLARIZE ULTRA COLD NEUTRONS

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Abstract

At RCNP, we have been developing magnets utilizing high-temperature superconducting (HTS) wires for this decade. Recently we fabricated a cylindrical magnet for a practical use which polarizes ultracold neutrons. It consists of 10 double pancakes and the field strength at the center is larger than 3.5 T which is required to fully polarize 210 neV neutrons. Design and performance of the magnet are described.

INTRODUCTION

High-temperature superconductor (HTS) materials were discovered in 1986 [1]. Significant effort went into the development of new and improved conductor materials [2] and it became possible to manufacture relatively long HTS wires of the first generation [3]. Although many prototype devices using HTS wires have been developed, so far these applications have been rather limited in accelerators and beam line facilities [4].

At the Research Center for Nuclear Physics (RCNP) of Osaka University, we started to investigate the performance of HTS wires applied for magnets excited by alternating current (AC) as well as direct current (DC) ten years ago. We have fabricated three types of magnets. They are a cylindrical magnet [5], a scanning magnet with race-track shape coils [6] and a super-ferric dipole magnet [7]. The coil of the dipole magnet has a negative curvature and the magnet successfully generated the field higher than 3 T at operating temperature of 20 K.

We have been developing a superthermal ultracold neutron (UCN) source to search for the neutron electric dipole moment (nEDM) [8-10]. The critical energy of UCN from the RCNP source is 210 neV which is determined by the Fermi potential of the He-II bottle. The neutron magnetic potential is 60 neV/T. Then the magnetic field is required to be larger than 3.5 T in order to fully polarize UCNs from the source. We decided to apply HTS wires for a practical use after our developments on HTS magnets.

Design and preliminary results of performance tests of the fabricated magnet are described in this paper.

DESIGN AND FABRICATION

We selected a commercially available first-generation HTS wire supplied by Sumitom Electric Industries, Ltd. The wire consists of a flexible composite of Bi-2223 filaments in a silver alloy matrix [11]. The magnet is built by stacking ten double pancakes and fixing them on a bobbin made of stainless steel. The design parameters are summarized in Table 1. The total length of HTS wire is 1530 m. Figure 1 shows a cross sectional structure of the upper half of the magnet.

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Table 1: Design Parameters of the HTS Cylindrical Magnet

Coil	Inner diameter	131.5 mm
	Outer diameter	213 mm
	Length	105 mm
	Number of DP	10
	Number of turns	2800
	Total length of wire	1530 m
	Inductance	1 H
	Weight	30 kg
Magnet	Operating Temperature	20 K
	Rated current	200 A
	Field at the center	3.5 T
Cryostat	Cooling power	35 W at 45 K 0.9 W at 4 K
	Temperature of the shield	60 K

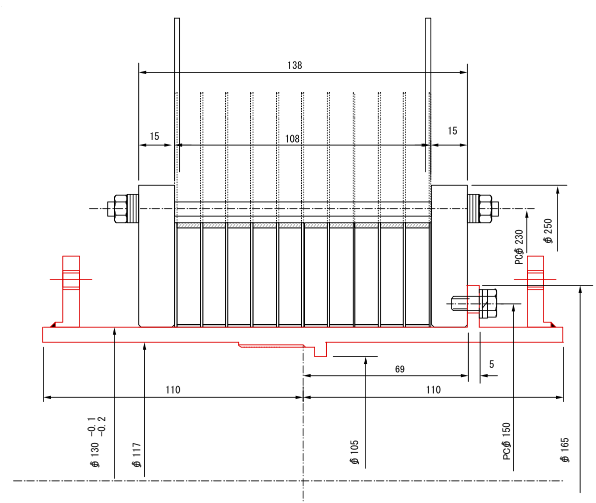

Figure 1: A cross sectional structure of the upper half of the cylindrical magnet. Each double pancake is sandwiched by 1 mm thick cooling plates made of cupper.

The critical current (Ic) of the HTS conductor depends on the operating temperature and the magnetic field at its

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surface. The magnetic field $B_\perp$ perpendicular to the conductor has larger effects on Ic than the horizontal field component. Before winding, the Ic of the wire over the full length was measured at 77 K in a 10 m pitch and found to be about 147 A corresponding to an electric field amplitude of 0.1 μV/cm. The Ic values of the coils were estimated from the Ic ($B_\perp$) characteristics of the tape conductor at and a magnetic field analysis using the finite element code TOSCA. The load line of the coil was found to cross the Ic ($B_\perp$) curve at 0.3 T and a current of 20 A corresponding to an Ic at 77 K. In the present design, the maximum field was 3.5 T at the center and the required magneto-motive force is 5.6 x 10^5 AT. The maximum field perpendicular to the tape surface is estimated to be 2.8 T. From the specification of the temperature dependence of the I($B_\perp$) characteristics, the Ic value was estimated to be 256 A at 20 K. The rated current of the coil was designed to be 200 A. The Ic of wounded coil was measured at 77 K and was 25 A. It is higher than the design value 20 K and the results shows no damages occurred on wire by winding. Figure 2 show the result of the Ic measurement at 77K. Figure 3 shows the coil fixed to the stainless steel bobbin.

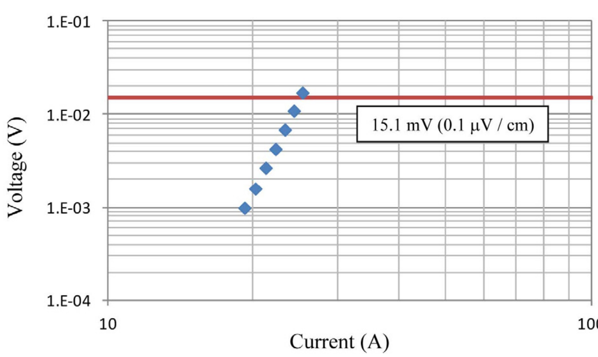

Figure 2: Results of Ic measurement at 77K. The total length of wire is 1530 m. The Ic value is 25 A which is better than the design value of 20 A.

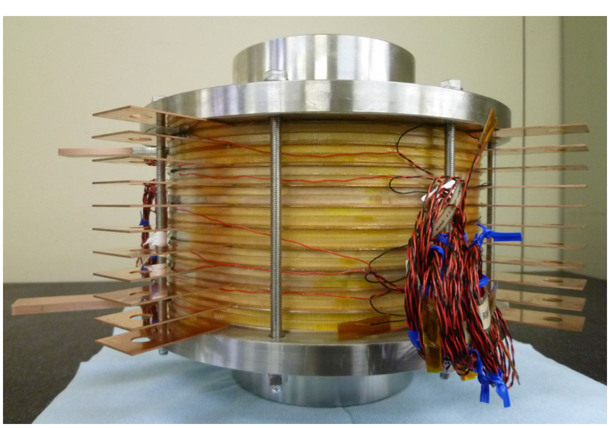

Figure 3: Photograph of the coil fixed to the bobbin.

PERFORMANCE OF THE MAGNET

The coil is installed in a cryostat which is covered by a magnetic shield made of 25 mm thick soft steel plates. The coil is covered by a thermal shield and 10 layers of super-insulation. The coil is cooled by a pulse tube cryocooler, RP-082B2S from Sumitomo Heavy Industries, Ltd. [12]. The shield and power leads are connected to the first stage whose cooling power is 35 W at 45 K. The coil is connected to the second stage whose cooling power is 0.9 W at 4 K. Figure 4 shows the cooling performance. The coil is cooled down to 13 K in 36 hours from the room temperature, which is lower than designed value of 20 K. The equilibrium temperature of the shield is about 60 K. The energy deposit form two power leads is estimated to be 14 W and is consistent with measurements.

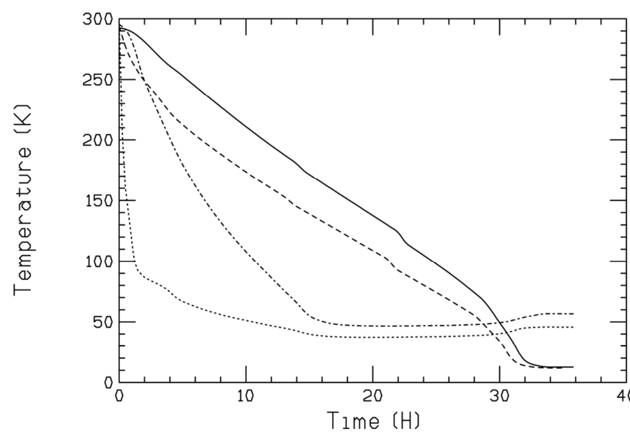

Figure 4: Cooling performance of the system. Solid, dashed, dot-dashed and dotted lines show the temperature of the coil, the first stage of the cryocooler, the shield and the second stage of the cryocooler, respectively.

Magnetic fields on axis were measured using Hall probe. A warm bore was installed for the measurement. Figure 5 shows the excitation results. At 200 A, the field was about 3.75 T which is higher than the expected strength 3.5 T. Figure 6 shows the field distribution along

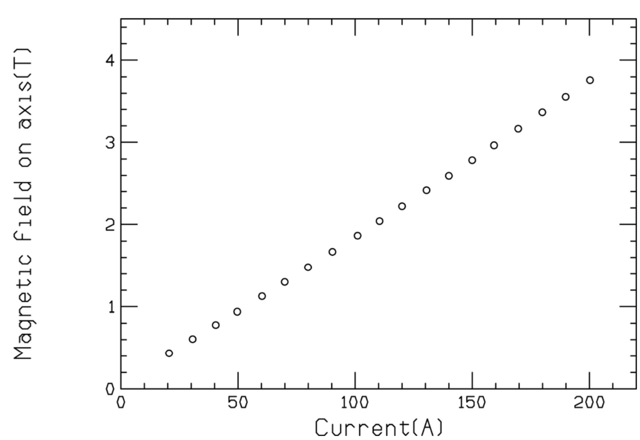

Figure 5: Excitation results of the fabricated magnet.

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the axis. The calculated values are normalized to the measured field at the center. The measured value is larger than the calculation by 3.5%.

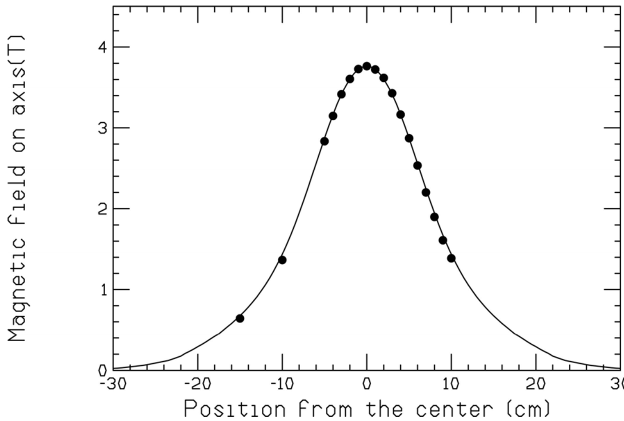

Figure 6: Field distribution along the axis. The solid line shows results of the numerical simulation by TOSCA.

The magnet was connected to the UCN source. Figure 7 shows the magnet connected to the UCN guide tube. A nEDM measument apparatus will be installed after the magnet. The cryostat is coved by the 25 mm thick iron plated to reduce the leakage field at the experimental apparatus.

Figure 7: Photograph of the cylindrical magnet installed downstream of the UCN source at RCNP. The nEDM measurement apparatus is placed after the magnet.

SUMMARY

At RCNP, we have developed HTS magnets for this decade. Recently we fabricated a cylindrical magnet for a practical use which polarizes 210 neV ultracold neutrons. The coil cooled by a pulse tube cryocooler to 13 K in 36 hours. The field strength was measured to be 3.75 T at the center which is larger than the requirement, 3.5 T.

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