DEVELOPMENTS OF HTS MAGNETS TOWARDS APPLICATION TO ACCELERATORS

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Abstract

We have been developing magnets utilizing first generation HTS wire for this decade. HTS materials have advantages over LTS materials. Magnets can be operated at 20 K or higher temperature and the cooling structure becomes simpler. Owing to a large margin in operating temperature, it is possible to excite HTS magnets by AC or pulsed currents without quenching. After successful performance tests of proto type models, two magnets have been fabricated for practical use. A cylindrical magnet generates a magnetic field higher than 3.5 T at the center to polarized 210 neV ultracold neutrons. A dipole magnet is excited by pulse currents in order to deliver accelerated beams to two target stations by time sharing.

INTRODUCTION

From the first discovery of high-temperature superconductor (HTS) in 1986 [1], research and development for new and improved conductor materials have been performed for decades [2]. It resulted in a possibility to manufacture relatively long HTS wires of the first generation [3]. For the second generation HTS wires and their applications, development for a reliable production process is carried on by many researchers nowadays. Many prototype devices using HTS wires have been developed, even though these applications have been rather limited in accelerators and beam line components [4] so far.

At the Research Center for Nuclear Physics (RCNP) of Osaka University, alternating current (AC) and direct current (DC) excitation for magnets using HTS wires have been studied for a decade. Five types of HTS magnets are fabricated in our facility. They are a cylindrical magnet [5], a scanning magnet with race-track shape coils [6], a super-ferric dipole magnet [7], a solenoid like magnet consisting of ten double pan cakes [8] and one-meter-size dipole magnet with race-track shape coils. The coil of the super-ferric dipole magnet has a negative curvature and the magnet successfully generated the field higher than 3 T at operating temperature of 20 K. First three magnets mentioned above are toy models, and the last two are practical applications.; an ultracold neutron (UCN) polarizer magnet and a beam switching magnet to make a time sharing of beams from the RCNP ring cyclotron. We selected a commercially available first-generation HTS wire, BSCCO-2223 supplied by Sumitomo Electric Industries, Ltd [9].

Designs and results of performance tests of those practical applications are summarized in this paper.

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UCN POLARIZER MAGNET

To polarize UCNs with energies lower than 210 neV, a cylindrical HTS magnet was constructed. Magnetic potential of the neutron is 60 neV/T. For full polarization of UCNs, magnetic field of larger than 3.5 T is required. The magnet was built with ten double pancakes (DP) stacked and fixed on a stainless steel bobbin. The design parameters are summarized in Table 3. HTS wire is 1530 meters in total length. A warm bore was installed for magnetic field measurement on the axis using Hall probe. The field distribution along the axis is shown in Figure 1. The field is higher than 3.5 T at the center. The UCN polarization was observed to be higher than 95 % which was measured with the RCNP-KEK superthermal UCN source [10] by passing neutrons through the magnet.

Table 1: Design Parameters of the UCN Polarizer Magnet

Coil	Inner diameter	131.5 mm
	Outer diameter	213 mm
	Length	105 mm
	Number of DP	10
	Numbers 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 center	3.5 T
Cryostat	Cooling power	35 W at 45 K
		0.9 W at 4 K
	Temperature of the shield	60 K

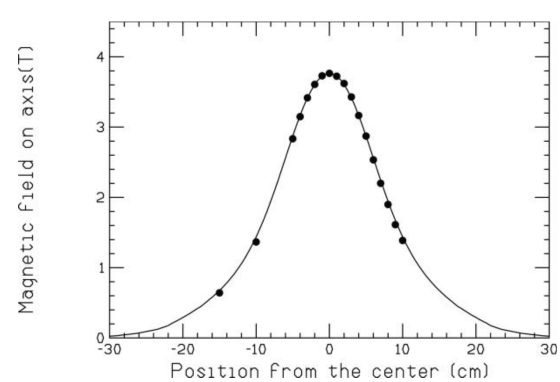

Figure 1: Field distribution along the axis. The solid line shows results of the simulation by TOSCA.

SWITCHING MAGNET

We have more beam time requests than available at the RCNP cyclotron facility. To provide more beam to users, beam sharing between two target rooms are planned, for example at the UCN and muon production targets. To put it into practice, a conventional normal conducting magnet will be replaced by a pulsed magnet which is shown in Figure 2. Based on the successful result of the model dipole magnet described above, we decide to apply the HTS wire for the magnet. Table 2 summarizes coil design parameters. The size of the race-track coil is 1,142 mm long and 580 mm wide. It is much larger than the model magnet. The magnet is currently under the performance test which gives us information on the mechanical and thermal stabilities of HTS coil in large scale.

Table 2: Design Parameters of the HTS Dipole Magnet

Coil	Inner size	1142 mm x 580 mm
	Number of DP	2
	Numbers of turns	256 x 2
	Inductance	2.5 H
Magnet	Temperature	< 20 K
	Rated current	200 A
	Field at center	1.6 T
Cryostat	Cooling power	16 W at 20 K
		2 W at 7.5 K
	Shield temperature	50 K

Figure 2: HTS switching magnet from downstream.

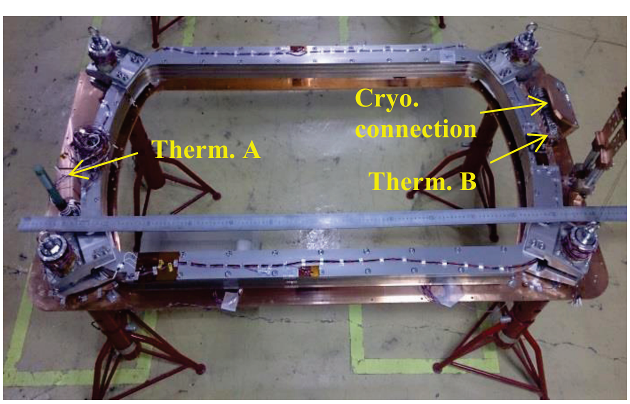

Figure 3: Upper coil assembly without thermal shields.

Figure 4 shows the initial cooling performance of the magnet. It takes 50 hours to cool the whole magnet down to operational temperature. Thermometer B is measured near the connecting point to a cryocooler and A at the far end of the coil assembly, as shown in Figure 3.

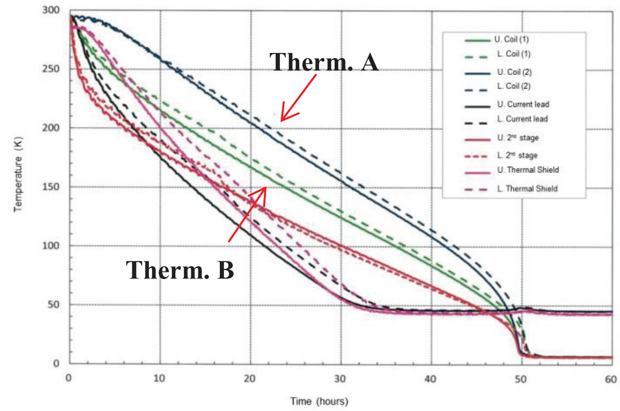

Figure 4: Initial cooling performance of the HTS magnet.

For time sharing of a beam, rapid excitation is required. The magnet's iron core is laminated and the power supply is designed to perform 20 A/s ramping with 2.5 H of the coil's inductance. A temperature history during a pattern operation is shown in Figure 5. Coil temperature stays in the operating temperature with a large margin during 30-second exiting and 60-second degaussing pattern. Figure 6 shows the saturated temperature after two hours of operation. The result confirmed the thermal design.

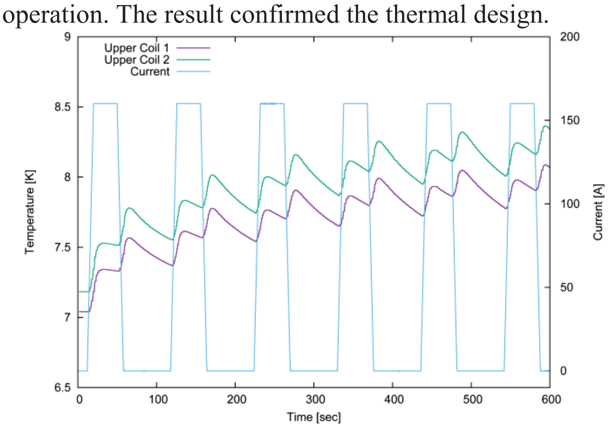

Figure 5: Temperature of upper coil during pattern operation.

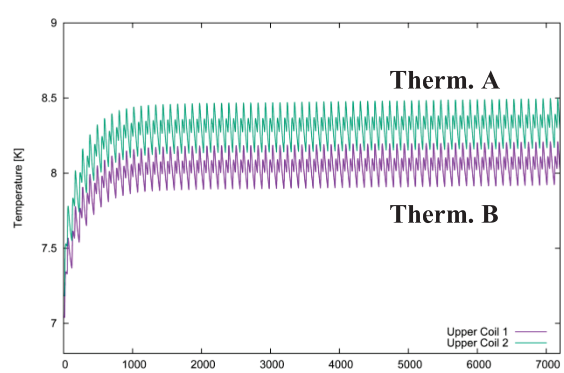

Figure 6: Temperature after 2 hours of the operation.

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Pole edges are cut into Rogowski curve to maintain the same effective field boundary over wide excitation level. Magnetic field strength distribution was measured by hall probe in each excitation level as shown in Figure 7.

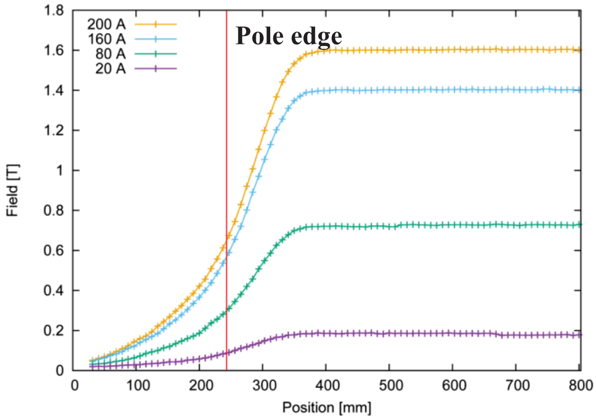

Figure 7: Field distribution for each excitation level.

To provide precise beam switching, stability in field strength is required. A pattern called cycling operation has been developed for the field stability, at 1.4 T by 160 A, current is raised up to 200 A for a moment and then lowered down to 160 A. It cancels the hysteresis of iron-core. Field strength is measured by NMR probe as time proceeds. Figures 8 and 9 are the results.

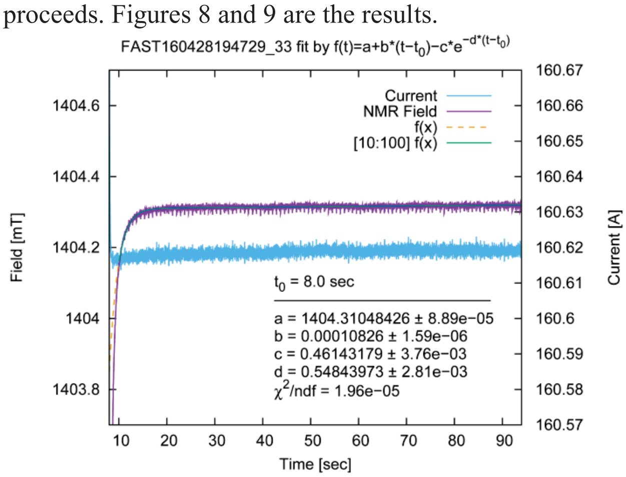

Figure 8: Field strength after excitation without cycling.

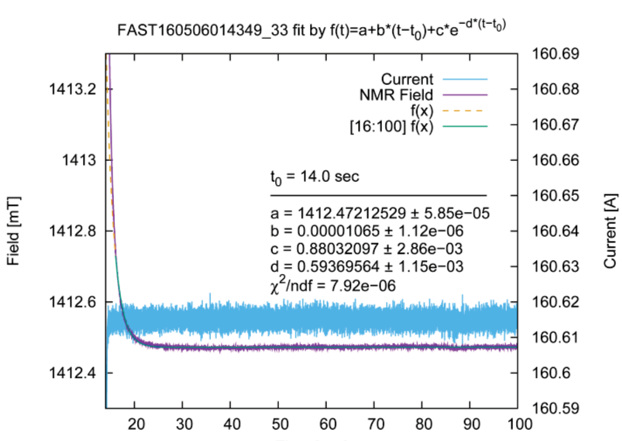

Figure 9: Field strength after excitation with cycling.

Fields are fit with a curve of linear and exponential functions. The constant b shown in Figure 8 and 9 shows the time dependence of the field in the flattop. Throughout two hours of operation, the value b without cycling is around 10^{-4} mT/s and always positive. On the other hand, it is around 10^{-5} mT/s and fluctuates back and forth around zero for each excitation. It indicates the effect of cycling operation.

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