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Design and fabrication of double pancake coil using 2G wire for conduction cooled superconducting magnet

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Abstract

A large bore double pancake coil(DPC) was designed and tested with 2G HTS wire to develop the conduction cooled superconducting magnet with central field intensity of 3 T at 20 K operating temperature and clear bore of 100 mm at room temperature. The effect of insulation between turns of double pancake coils was tested. Two double pancake coils with and without turn to turn insulation were wound using 4 mm wide 2G conductor. A temporary result suggests that the coil wound without electrical insulation can be protected from higher over current and shows improved stability.

Keywords: conduction cooled magnet; 2G wire; double pancake coil; stability; quench; Cryogen free

1. Introduction

Superconducting(SC) magnet has been the most successful application of superconductivity and secured sizable market. SC magnets are widely used in biomedical devices and R&D facilities such as NMR, MRI, accelerators, and fusion reactors. With the advent of high-T_C superconductor(HTSC), it was hoped that SC magnets which can be operated at higher temperature would be available soon, thereby reducing the operating costs. But many years of research was needed before HTSC wires are available for meaningful application.

Although liquid Nitrogen is cheap enough, it is desirable to operate SC magnets without liquid cryogen, for cryogen recharging may cause inconvenience and interruption to the experiment.[1,2,3,4] In this paper, we describe our efforts to design and construct conduction cooled HTSC magnet. Recently pancake coil without turn-to-turn insulation was suggested, and shown to have superior stability against over-current.[5] We fabricate two double-pancake coils(DPC) one with turn-to-turn insulation, the other without it, and measured their electrical properties and field behavior. Measurement results are presented, and implications to magnet stability are discussed.

2. Magnet Design

We designed HTSC magnet with the center field of 3 Tesla and coil diameter of 140 mm, so that we have room temperature bore of more than 100 mm diameter. Other design constraints are; i) wire length for a single DPC be

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around 100 m, which is not-so-hard-to-obtain piece-length of current 2^{nd} generation(2G) HTSC wire; ii) maximum perpendicular field be less than 2 Tesla, so that operation current will exceed 150 A above 20 K; iii) field variation be less than 0.1% within 1 cm diameter spherical volume(DSV). Table 1 gives resulting magnet parameters.

Table 1. Design parameters of the magnet

Parameter	Value
Conductor width; thickness (mm)	4.0; 0.218
Number of DPC	22
Turn per pancake	110
Winding i.d.; o.d. (mm)	140; 188
Height (mm)	244
Conductor length per DPC (m)	113.5
Operating Current (A)	150

Fig. 1 shows magnetic field profile calculated with the above parameters. Magnetic field variation was found to be 0.064% in 1 cm DSV at the center, satisfying our design criteria.

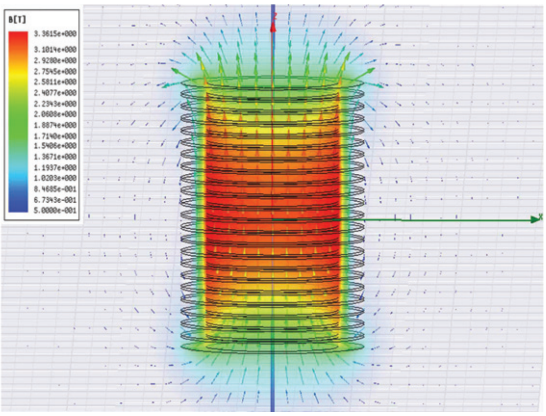

Fig. 1. Calculated field profile of designed magnet.

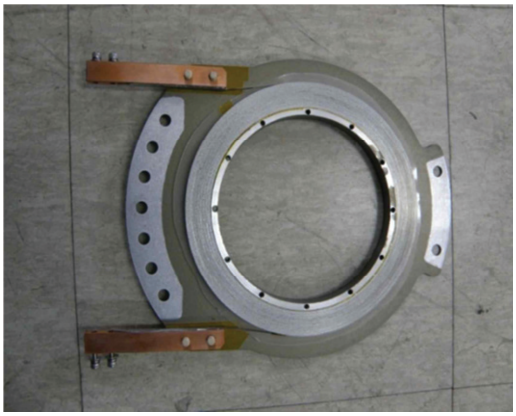

Fig.2. Photograph of a double pancake coil.

3. Double pancake coil characterization

We tested two kinds of double-pancake-coil(DPC) before making the whole magnet, with and without turn-to-turn insulation. Fig. 2 is a photograph of a DPC with only lower plate attached to the bobbin, upper plate being removed to show the coil. Each DPC parameters are listed in Table 2. GdBCO tape was used as the conductor, and turn-to-turn insulation was accomplished by co-winding 2G wire with Kapton film of 25 μm thick.[6] Upper and lower plates are anodized for electrical insulation. And G10 plate is inserted between pancakes, Fig.3 is an electrical circuit diagrams.

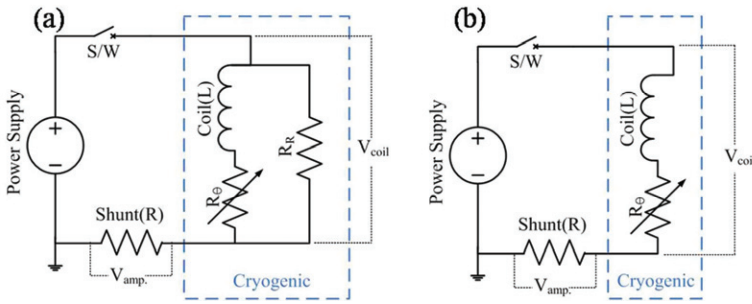

Fig. 3. Electrical circuit diagram of (a) without turn to turn insulation, and (b) turn to turn insulation: R_θ (azimuthal resistances of HTS tape); and R_R (radial resistances)

Table 2. Parameters for double pancake coil with and without turn-to-turn insulation

Parameters	DPC with insulation	DPC without insulation
Conductor	Brass laminated(40 μm)	Brass laminated(40 μm)
	CC(GdBCO)	CC(GdBCO)
Turn per pancake	85	117
Winding i.d.; o.d. (mm)	140; 177	140; 185
Conductor length per pancake (m)	84	119
Coil critical current @ 77 K (A)	55	55

Each DPC was characterized by monitoring magnetic field at the center and the voltage between terminals with applying current as shown in Fig.3 DPC being immersed in liquid nitrogen. Fig. 4 shows applied current to the coil and resulting magnetic field for DPC with insulation. Magnetic field is proportional to the applied current at the moment as is expected.

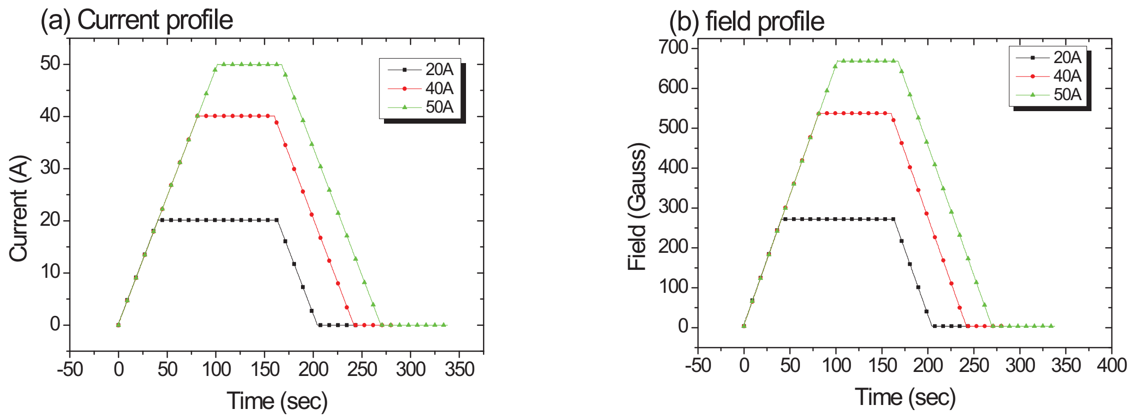

Fig. 4. (a) current profile, and (b) field profile for DPC with insulation

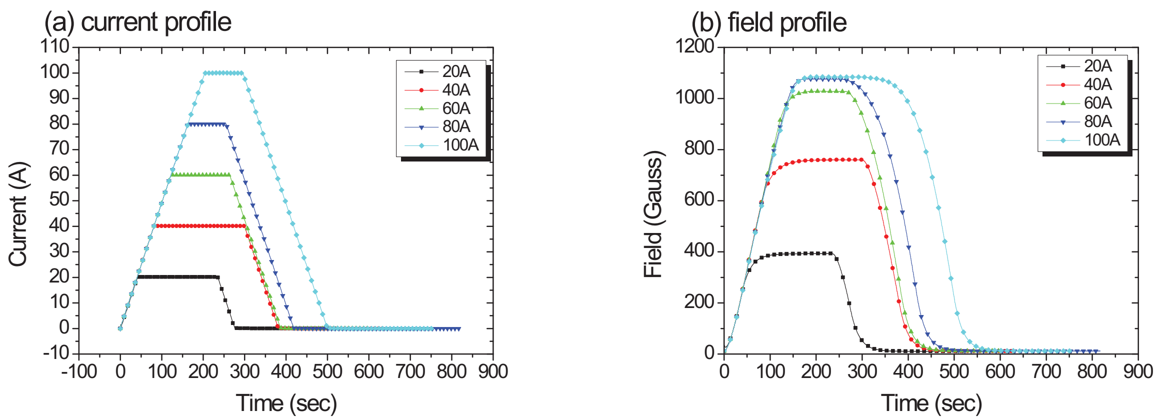

Fig.5 (a) current profile, and (b) field profile for DPC without insulation

Fig. 5 depicts applied current to the coil and resulting magnetic field for DPC without insulation. Contrary to the DPC with insulation, magnetic field lags behind applied current because current bypassing from one turn to the next experiences less impedance than coil reactance when the current is ramping. When the applied current exceeds coil critical current, magnetic field begin to saturate, but the coil still acts as a magnet without damage. This implies that magnets comprised of DPSs without insulation could be more stable against over-current, as reported by other groups[5].

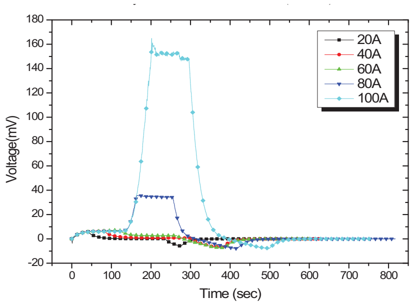

Fig.6. Voltage profile for DPC without insulation

Fig. 6 shows voltage between terminals for DPC without insulation. Note that the voltage is unstable at the applied current of 100 A. Seungyong Hahn *et al*.[5] reported that over-current voltage is stable for no-insulation pancake coil and unstable for pancake coil co-wound with Hastelloy. In our case voltage instability is thought to arise from rather poorly defined contact between pancakes, with neither deliberate insulation nor well-defined electrical contact. We're making DPC without turn-to-turn insulation, but with pancake to pancake insulation inserted to further our understanding.

Table 3. Rate of saturation field

Current (A)	Axial field (Gauss)	Saturation rate (%)
20	375	51.8
40	724	71.7
60	1009	94.5
80	1068	99.4
100	1074	100

Table 3. and Fig.5(b) presents center field increases linearly up to 60A but saturates at 1068 and 1074 gauss at 80A and 100A, respectively. This coil was saturated at higher current than critical current because most of the current was bypassed through turn to turn contacts. Operation current was 1.8 times larger than coil critical current. Therefore, without-insulation-coils winding may enable a compact HTS magnet with better thermal stability as well as enhanced mechanical integrity.

4. Conclusion

We designed 3 Tesla center-field magnet and simulated field profile to check that the magnet would work as designed. We tested DPC with and without turn-to-turn insulation and found that DPC without insulation generates stable magnetic field under over-current and is appropriate for use for magnet. But voltage is found to be unstable and is attributed to the absence of pancake-to-pancake insulation, to be confirmed with further experiments.

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