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Research paper

Screening current induced magnetic field in REBCO superconducting coil wound by using split wire having intermittent inner split

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ABSTRACT

REBCO-coated conductor having a high critical current is promising for applications in next generation apparatuses such as ultra-high field NMR, high-resolution MRI, and high-precision accelerator. However, it has an important challenge for application in NMR and MRI, due to the single core in REBCO superconducting layer. The single core induces a large screening current-induced magnetic field (screening current field), and it influences the controlling of center field in NMR/MRI magnet. To reduce the screening current field, we have recently developed a split wire having multi-core structure by inner split method (electrical separation by bending stress, ESBS). In experiment, short samples with linear inner split by a large bending stress of 80 N were prepared and tested. However, to fabricate a long length wire with good quality, it is better to use a smaller bending stress. In this study, a low-bending-stress inner split method is used to fabricate superconducting tapes with longitudinal split in their superconducting layer. The fabrication and experimental assessments for the wire and coil are carried out.

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1. Introduction

Recent advances in $REBa_2Ca_3O_{7-\delta}$ (REBCO, RE: rare-earth)-coated conductor, referred to as second-generation high temperature superconductor (2G HTS), have resulted in high critical current density and high mechanical strength, such as critical current by above 3000 A/mm^2 (at 12 T) and tensile strength of about 700 MPa (SuperPower Inc.). However, REBCO coated conductor still has several challenges for use in NMR and MRI [1,2], such as a large screening-current induced magnetic field (screening current field) in the coils, a degradation of critical current in REBCO coil by epoxy impregnation, and a thermal runaway by over current. For the last two problems, there are now some effective solutions [3,4], but the first has not yet been solved. To reduce the screening current field, scribing the tape to produce several filaments such as by mechanical methods, laser scribing or chemical etching have been proposed [5,6]. However, scribed wire has lower tensile strength, which we have seen to be as low as below 300 MPa in our experiments [7]. In terms of overcoming the large hoop stress issue in the high-field magnet, high tensile strength (i.e. above 500 MPa) is important.

Recently, we developed a REBCO split wire having a high tensile stress tolerance similar to original wire [7]. In this paper we report on wire fabricated with a linear inner split (perfect separation of REBCO filament) and long-length wire with intermittent inner split, essentially forming a dashed line in the REBCO layer. We assessed critical current for both wire types, and screening current field for a coil wound using the intermittent split wire.

2. Experimental details

2.1. Fabrication of samples

The split wire is fabricated by electrical separation by bending stress (ESBS) [7] using a desktop splitter, as shown in Fig. 1(a). The difference between splitting and slitting processes are shown in Fig. 1(b), (c), and (d). Splitting is considered to be a superior process to mechanical slitting in its ability to maintain the original high mechanical strength. It is critical in the fabrication process of split wire to prevent frictional forces from delaminating the tape, which is accomplished by moving the slitter and wire simultaneously. It is possible to split only the ceramic layer (REBCO and buffer layers) in the coated conductor, by exploiting the difference in toughness between the ceramic and metal (Hastelloy substrate, copper laminate, and silver layer). As a precursor, a 4 mm wide and 0.09 mm thick REBCO coated conductor manufactured by SuperPower Inc.

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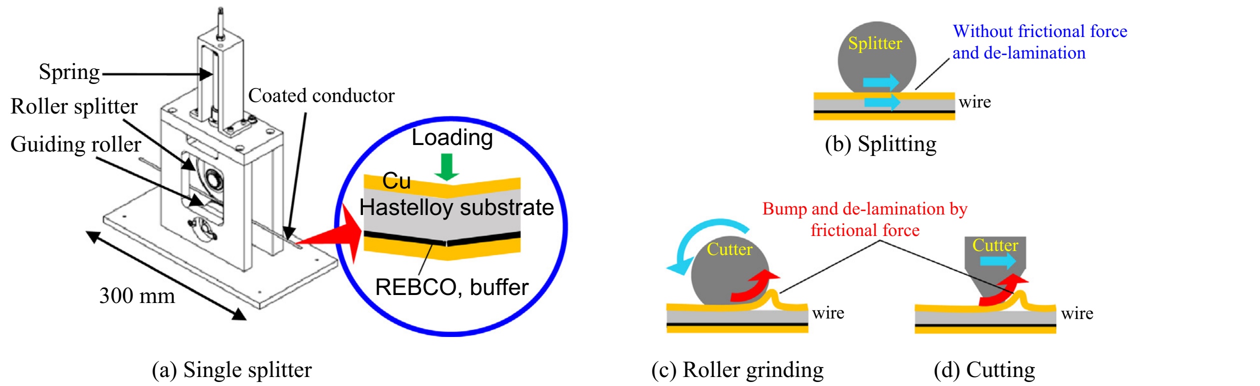

Fig. 1. Illustration diagrams of (a) single splitter for fabrication of split wire and (b–d) deference between splitting and mechanical scribing. Inset in (a) is cross-section image of the wire in inner split fabrication process by bending form Hastelloy side. In the fabrication of split wire as shown in (b), it is almost no frictional force to parallel to the tape surface, since the wire and splitter move simultaneously. It is different form the scribed wire by mechanical slitting that usually has frictional force causing de-lamination to remove other layer at slit, as shown in (c) and (d), which is a reason keeping the high mechanical strength better than mechanical slitting.

was chosen to prepare the split wire having intermittent inner split. Multiple inner splits were fabricated by changing the bending position [7]. To achieve the proper bending direction, the blade edge makes contact with the Hastelloy side as shown in the inset of Fig. 1. The degree of separation of the REBCO filaments is related to the downward load applied by the blade.

To determine the appropriate load value, various loads were applied in the inner split fabrication process, and the *I-V* properties between adjacent filaments were measured. In the results as shown in Fig. 2, a linear behavior appears in load of 60 N, indicating that perfect electrical separation without superconducting current flow between REBCO filaments is formed. However, it is better to reduce the load value by slightly restoring the extended spring in the fabrication process to obtain a long-length wire for fabrication of magnet coil. In this study, a load of 45 N was chosen to prepare 6 m long split wire for coil test. Using a load of 45 N, the critical current between two filaments is about 5 A for 1 cm length of wire at 77 K (without external field), as seen in the Fig. 2. This results in an intermittent electrical separation with small superconducting current flow between REBCO filaments. The effect of the intermittent electrical separation on screening current field of coil is estimated in this study. Specifications of original and split wire coils using this technique are listed in Table 1. A picture of the coil wound by split wire (coil B) is shown in Fig. 3.

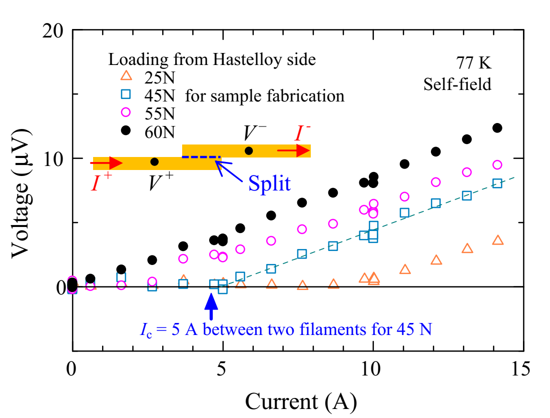

Fig. 2. *I-V* properties between two filaments in wire. After perform a split along longitudinal direction of wire (wire width of 4 mm), opposite side of half wire was removed to measure the voltage between two filaments as inset figure (four-point probe method). Distance between two voltage taps V^+ and V^- is 1 cm. The samples were measured at 77 K in self-magnetic field.

Table 1
Specifications of coils.

	Coil A	Coil B
Type of wire	SuperPower SCS 4050	
Thickness of wire (mm)	0.094	
Width of tape wire (mm)	4.0	
Total length of wire (m)	6	
Load for inner split (N)	–	45
Core number of wire	1 (non-inner split)	6 (5 inner splits)
Coil winding shape	Solenoid	
Coil I.D./O.D. (mm)	30.0/31.5	
Coil turn number/layer	11/5	
Coil height (mm)	47	
Insulation	Co-winding with 0.035 mm thick Kapton tape	

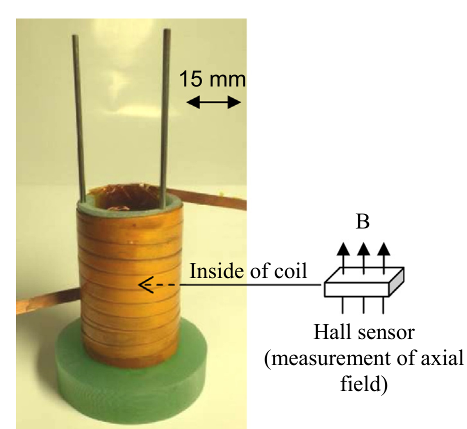

Fig. 3. Helical coil wound by using the split wire. Hall sensor was attached at inside of the coil (coil center) in measurement.

2.2. Measurements

The *I-V* characteristics of samples were measured at 77 K (without external magnetic field), for which the criterion of critical current (I_c) was defined as 1 μV/cm. After the measurement of critical current, the temperature of the coil was increased to room temperature to remove the residual field (screening current field) induced in the REBCO superconducting layer. Then the coil was cooled in liquid nitrogen (77 K) to measure the screening current field. A Hall sensor (F.W. Bell Ltd) was set in the coil center to measure the magnetic field in axis direction of coil. The magnetic field was

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