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Development of a 25 T All Superconducting Magnet with Small-Scale YBCO Insert Coil

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ASIPP

INTRODUCTION

The Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) started extremely high field HTS magnet project in 2017 to explore high field magnet technology and study the REBCO tapes performance beyond 20 T.. A 25T all superconducting magnet designed as a combination of 11 T HTS insert coil and a 14 T LTS background magnet was developed. The insert coil, based on the NI technique, consists of a stack of ten single pancakes wound with 0.1-mm thick YBCO tapes. The detailed design, fabrication and final test results of the insert coil will be reported in this paper.

YBCO INSERT DESIGN

A. Coil Structure

The YBCO tapes for the insert coil were supplied by Shanghai Superconducting Technologies Co., Ltd (SSTC), with a cross section of 5 mm × 0.1 mm. Detailed parameters of the YBCO tapes are shown in Table I.

TABLE I: PARAMETERS OF THE YBCO CONDUCTORS

Parameters	Unit	Value
Width	mm	5
Thickness	μm	100
Substrate /thickness	μm	Hastelloy/50
Stabilizer / thickness	μm	Copper/45
Matrix/ thickness	μm	Silver/1.5
Min. winding diameter	mm	15
Critical stress@77K	MPa	>530
Critical strain@77K	%	0.32%
Ic@77K, self-field	A	250

TABLE II: PARAMETERS OF THE YBCO INSERT COIL

Parameters	Value
Coil height	60 mm
Winding inner diameter	16 mm
Winding outer diameter	54 mm
Number of single pancake	10
Total number of turns	1900
Total tape length	220 m
Operating current	320A
Max hoop stress	383 MPa
Max Br	3.52T
Inductance	38.8 mH

With double-pancake winding without an inner joint, a compound bend of the conductor involving out-of plane and in-plane bending is required. The total strain of the compound bending is very large and the critical current of YBCO tapes decrease sharply. The relevant experimental results at 77K in self-field are shown in Fig. 1. All coils were wound as single pancakes to avoid in-plane bending of YBCO tape.

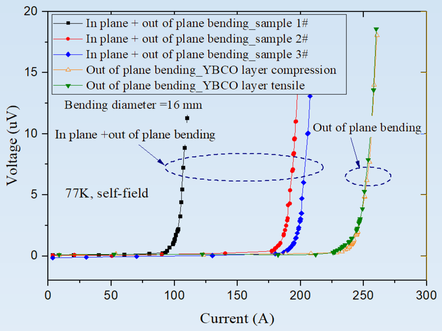

Fig. 1. Critical current of YBCO tapes under different bending modes.

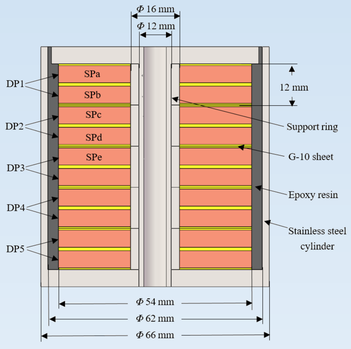

Fig. 2. The configuration for the YBCO insert coil.

The insert coil consists of a stack of ten single pancakes (SP) of the same size. Two adjacent single pancakes are electrical-ly connected by internal joints to form a double pancake (DP). Key parameters of the coil are listed in Table II. The configuration for the insert coil is illustrated in Fig. 2.

B. Mechanical Analysis of YBCO Insert

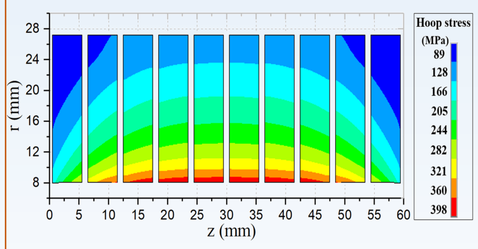

Fig. 3. The distribution of hoop stress due to electromagnetic force.

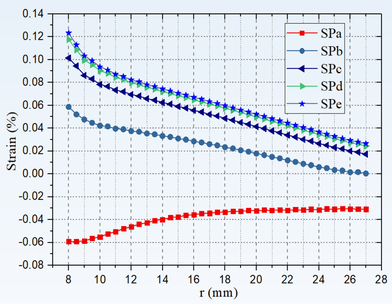

Fig. 4. The distribution of the sum of electromagnetic and bending strain.

As shown in Fig. 3, the maximum hoop stress is about 398 MPa, locates at the innermost layer of DP3. The sum of electromagnetic and bending strain under operation conditions is given in Fig. 4. The total peak strain is 0.12%, which is lower than the critical strain of YBCO tapes and will not be enough to cause the degradation of the coil performance.

FABRICATION OF YBCO INSERT

A. Pancake Construction

Each single pancake was wound with about 22 m of non-insulated YBCO tapes with a preload force of 20 N. The winding of the single pancake is shown in Fig. 5. For the internal joints, three parallel-arranged bridge joints were employed to connect YBCO tapes from two adjacent single pancakes, and three short pieces of YBCO tapes were used as bridging tapes as illustrated in Fig. 6.

B. Insert Assembly

All DPs need to be tested at 77 K after winding, and their performances have good consistency. After five DPs were stacked on the insulated stain-less steel bore tube, the outer bridge joints were soldered with 10-mm wide YBCO conductors to electrically connect the adjacent DPs. A stainless steel cylinder on the outside of the coil was used to resist electromagnetic forces. Finally, the insert coil was impregnated with epoxy resin at room temperature and atmospheric pressure to improve the mechanical stability of the coil. The insert coil after assembly and coil testing de-vice are shown in Fig. 7.

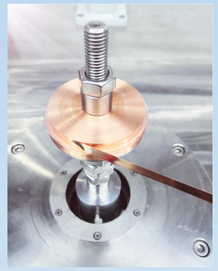

Fig. 5. The winding of the single pancake.

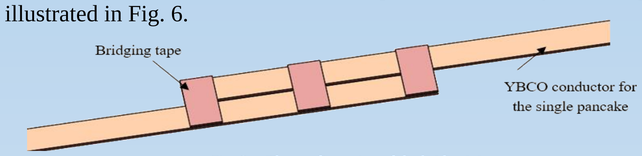

Fig. 6. The configuration of the bridge joints.

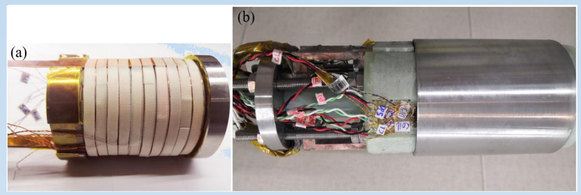

Fig. 7. (a) The insert coil after assembly. (b) The coil testing device.

TESTS AND RESULTS

A. Test at 77 K

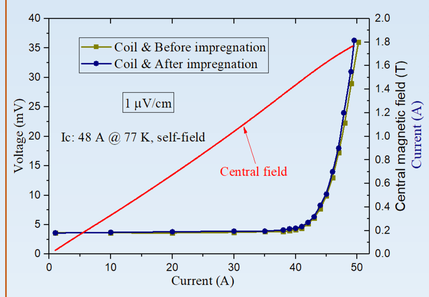

Fig. 8. Test of the insert coil at 77 K, self-field.

As shown in Fig. 8, no degradation of coil performance was observed during the impregnation process. In addition, the critical current is 48 A using the 1 μV/cm criterion and the coil can generate the central field of 1.72 T.

B. Test at 4.2 K

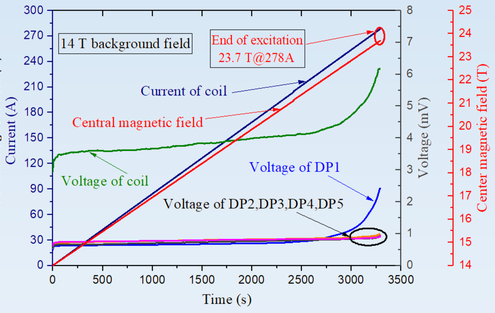

Fig. 9. Test results of the insert coil at 4.2 K in the 14 T background field.

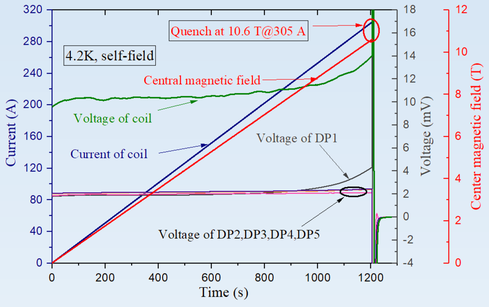

Fig. 10. Test results of the insert coil at 4.2 K in self-field.

As the applied current increased to 232 A, the superconducting transition first occurred on DP1 (top). The other double pancakes were also induced to undergo superconducting transition when the current increased to 278 A. At this time, the excitation was finished due to the higher power dissipation and the coil did not quench. The total steady-state central magnetic field is 23.7 T at 278 A.

As shown in Fig. 10, the voltage behaviors of the five DPs are very similar to that in 14 T background field. However, as the current increased to 305 A, the YBCO insert coil quenched due to poor performance of DP1. The maximum central magnetic field is about 10.6 T and the maximum perpendicular field is 3.43 T. Owing to the very fast electromagnetic quench propagation and small peak voltage, the insert did not experience electrical burn-out.