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Characteristics of the Critical Current Capabilities of an Stepped Grooves Structure Superconducting Conductor with Stacked REBCO Tapes

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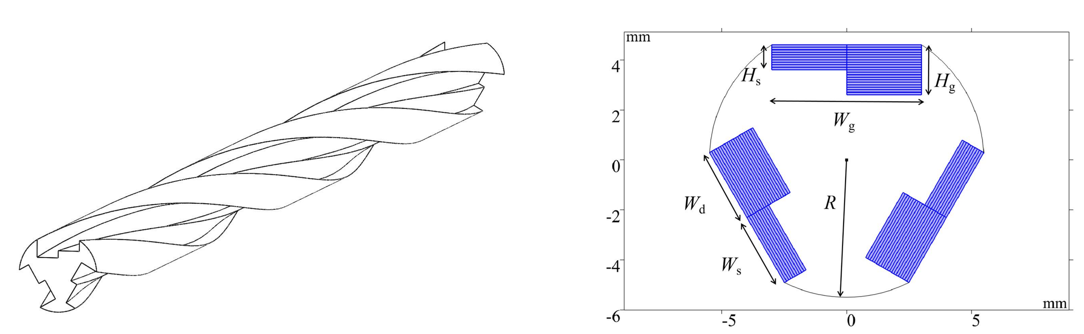
ABSTRACT

In this paper, a compact twisted stack tape cable (TSTC) with stepped grooves was performed. The stepped groove is divided into long groove and short groove with different number of tapes, and a long copper plate is sandwiched between the two stacking tapes to improve stability, while contributing to distribute fault current. Numerical studies of current-carrying capability and magnetic behavior of these cables have been carried out by employing a T-A formulation model and a H-homogenized formulation model. The effect of the quantity of grooves and tapes on the critical current is studied by the finite element method, respectively. Then, the sample of HTS TSTC cable with three stepped grooves is fabricated and tested.

INTRODUCTION

- To meet the application requirements of high magnetic field and high current in future fusion magnet systems, a compact twisted stacked tape cable with high current density is proposed.
- The innovative feature of this design is the division of the groove into long and short segments, each accommodating different numbers of superconducting tapes.
- This innovative configuration aims to distribute the magnetic field and current more uniformly, thereby improving the cable's overall efficiency. The stepped grooves are designed to accommodate a specific arrangement of YBCO tapes—20 tapes in the long groove and 10 tapes in the short groove—allowing for a comprehensive analysis of their electrical characteristics.
- By utilizing the finite element method (FEM), we systematically investigated the impact of varying the quantity of grooves and tapes on the critical current.



Structure of the proposed HTS TSTC with three stepped grooves

DESIRED PERFORMANCE [1]

- Stability against critical current degradation under mechanical and thermal cycling;
- High cryostability and reliable quench detection techniques;
- Simple, low resistance, and manufacturable electrical joints.

REFERENCE

[1] Hartwig, Zachary S., et al. "VIPER: an industrially scalable high-current high-temperature superconductor cable." *Superconductor Science and Technology* 33.11 (2020): 11LT01.

SIMULATION OF STACKED TAPES

- The case of stacking 10 superconducting tapes is considered firstly. The size of a single superconducting tape is 3 mm * 0.1 mm, and the critical current at 77K is 120A. Its resistivity can be represented by the E-J characteristic as:

$$J_c(B_{perp},B_{para})=\frac{J_{c0}}{\left(1+\frac{\sqrt{k^2B_{perp}^2+B_{para}^2}}{B_0}\right)^{\alpha}}$$

- The simulation results indicate that the critical currents obtained by both T-A and H methods are 1006 A. Fig. 1 and Fig. 2 shows the B and J distributions and exhibit good consistency.

RESULTS

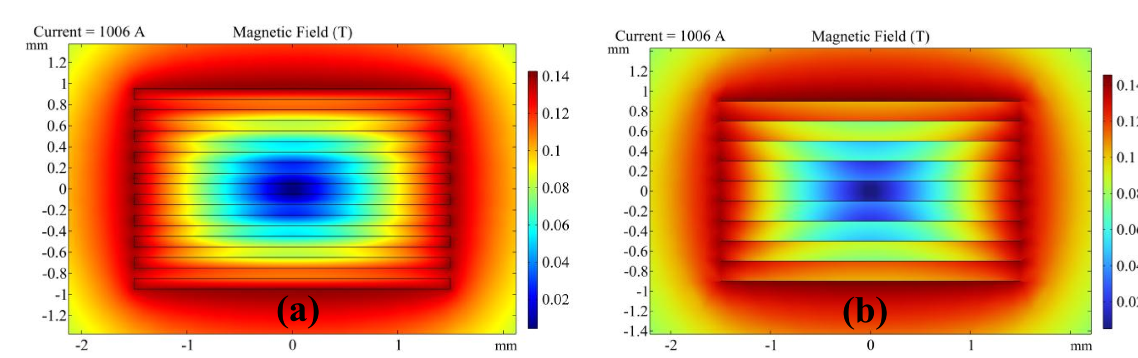


Fig. 1: Magnetic field distribution using (a) H method and (b) T-A method.

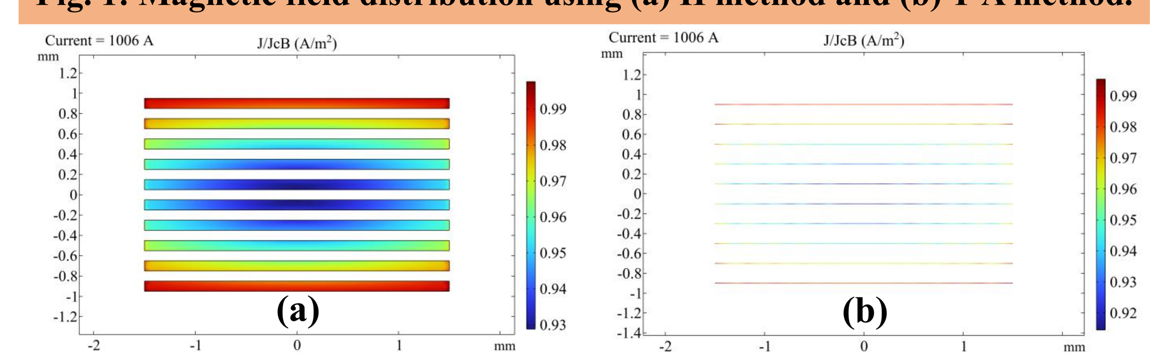


Fig. 2: Current density distribution using (a) H method and (b) T-A method.

STEPPED GROOVE CABLE WITH STACKED REBCO TAPES

- Considering that H method has higher accuracy in principle, subsequent simulations will be conducted using the H method.
- Fig. 3 shows the magnetic field distribution of grooves 2, 3, and 4 at the critical current when the former diameter remains constant. The critical current from situation are 5490 A, 8090 A and 10550 A, respectively. As the number of grooves increases, the critical current significantly increases, but the average critical current of a single tape decreases due to the increased self-field.
- From Fig. 4, when the number of grooves is constant, the critical current increases approximately linearly with the increase of the number of superconducting tapes.

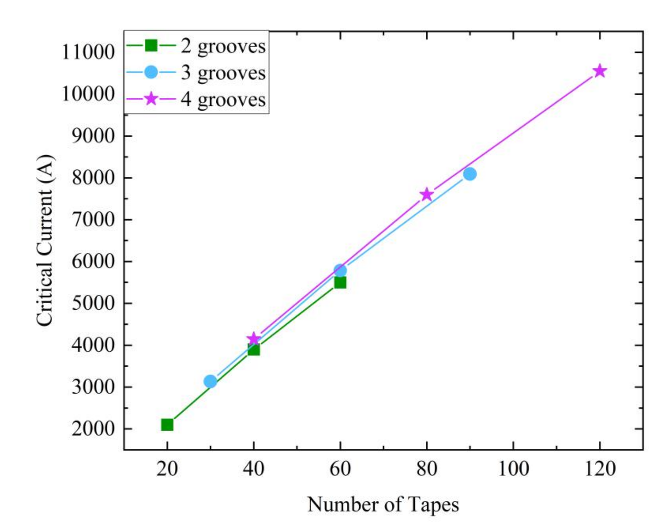


Fig. 4: The influence of different numbers of grooves and tapes on critical current.

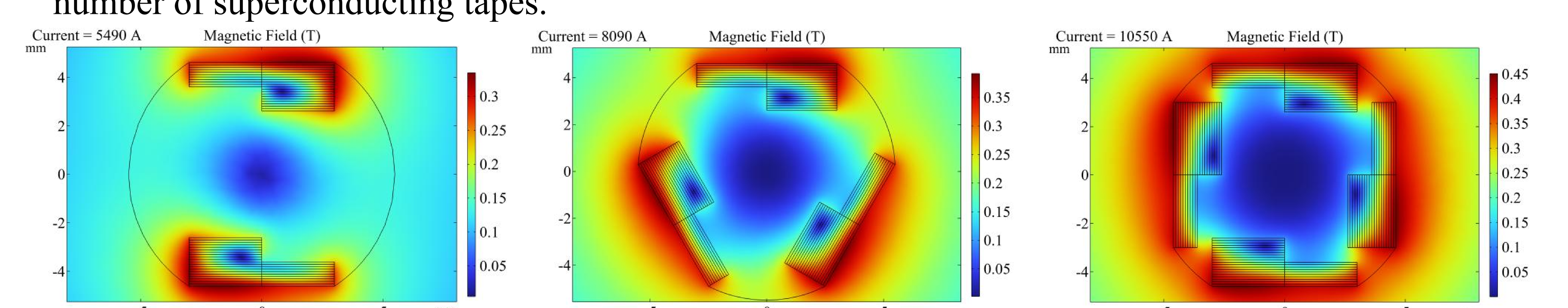


Fig. 3: Magnetic field distribution of stepped groove TSTC with different grooves.

EXPERMENT RESULTS

TSTC CABLE FABRICATION

- A sample with a length of 1 meter and a pitch of 300 mm.
- Consists of 18 superconducting tapes and 72 copper tapes.
- Copper collars are designed to secure the tape in place and removed after tapes are embedded into the former.

RESULTS

- The current ramping rate is set to 10 A/s, and the experiment is repeated to get two E-I curves. The results are 1920 A and 1900 A, respectively.
- The measured results are approximately 1980A of the simulation results.

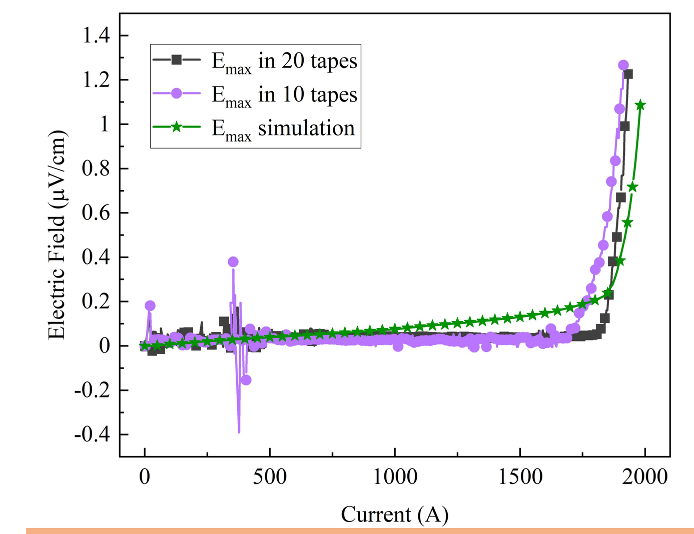
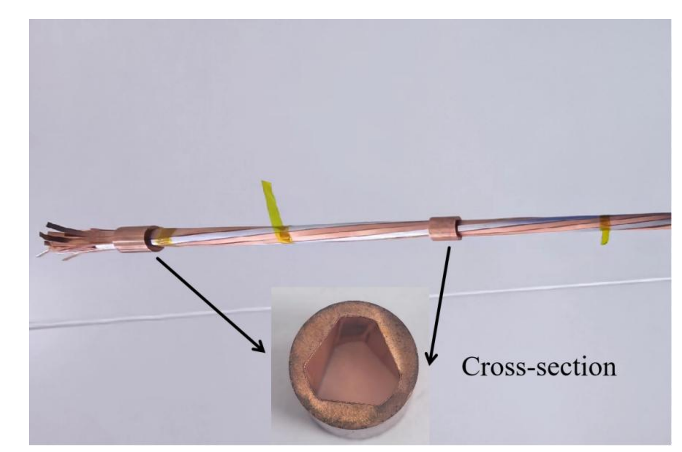
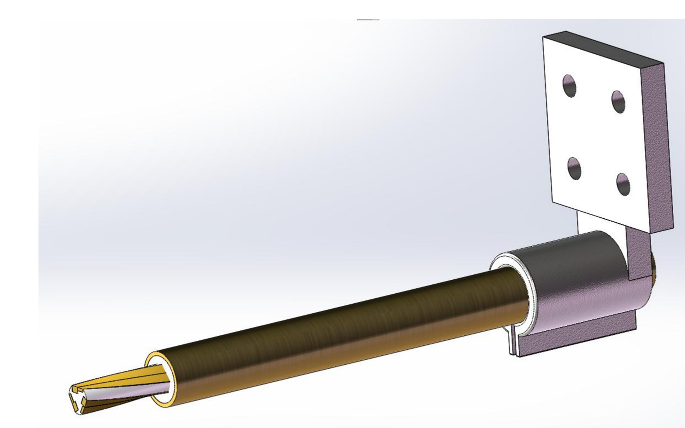


Fig. 5: E-I curves of experimental and simulated results.



Sample Cable



Terminal Joint

CONCLUSION

This article proposes a TSTC cable structure with a stepped groove, which has a higher current density than traditional structures. Firstly, its electromagnetic characteristics were studied through simulation, and a sample with three stepped grooves was fabricated. After conducting current experiments, the critical current and simulation prediction results are basically consistent, proving the feasibility of this structure. In our subsequent work, we will optimize the step size to achieve the best current carrying performance.