Analysis of contact behavior in CORC® cabling and under axial tension

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***Abstract*—CORC® cables or wires are composed of helical wound HTS REBCO tapes in multiple layers with high flexibility. However, compared with traditional multi-filament cables, the helical tape structure also brings new challenges to predicting the CORC® will be subjected to radial extrusion and circumferential stretching due to the electromagnetic force's action during operation. In this study, starting with the cabling process, the deformation of the tape, the normal contact force and friction distribution between the tape and the core are described. The effect of different winding parameters, such as core radius and winding helix angle, are obtained by combining theory and Finite Element Method (FEM) simulation. Then axial tensile loading of the multilayer CORC® is simulated and compared with the experimental curve including its critical current degradation. The results describe the interaction between tape and core that occurs during the tensile loading. The tape and the core are extruded and friction is generated, directly causing critical current degradation. The developed analytical and FE models can predict the mechanical and electrical properties of CORC® cables.**

Keywords—CORC®, cable, wire, REBCO, HTS, Finite Element Method, modeling, normal contact force, friction, critical current.

I. INTRODUCTION

The work on CORC® cable and wires is categorized into two sections.

A. Winding process of CORC® and Pancake coil

To produce CORC® cables and Pancake coils, the REBCO tapes are wound around a center core with a particular helix angle or under only few degrees. During the winding process, the tape's deformation is affected remarkably by the contact with the core. This affects the critical performance because the REBCO tape is strain sensitive. The mechanical properties of Pancake coils and CORC® cables are related to the initial contact during winding. The interlayer contact resistance is also a critical electrical property, since it determines the ability of current sharing and therefor the cable's stability. However, the winding is a rather complex process because of the combined deformations and its strong non-linearity, which leads to difficulties in calculating the contact force.

A two-dimensional simplified winding model of a Pancake coil is established through theoretical methods, considering the two main factors in the winding process; Relaxation and Poisson effect (longitudinal stress produces transverse deformation). The model contains two defined main regions: the core and the REBCO tape. The core is the rigid domain and the tape is the solution domain. One end of the tape is fixed to the core's surface and the other end is given a pre-tension force F_{pre}. The rigid core is designated to rotate. The model is shown in Fig 1.

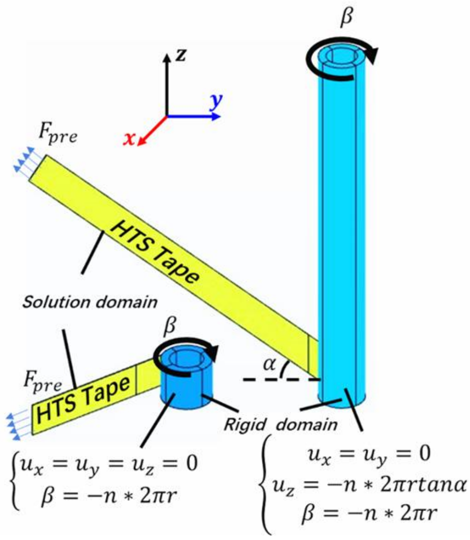

Fig 1: Pancake coil and CORC® cable winding model with boundary conditions.

As a result, the contact behaviour between the tape and the core is obtained. Then, the three-dimensional winding model is established by COMSOL software to analyse the contact behaviour between HTS tapes and center core. After describing the Pancake coiling and the CORC® cabling processes, the contact stress distribution is calculated using the FEM model (see Fig 2).

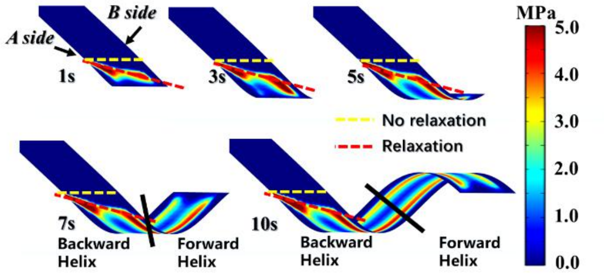

Fig 2: The process of CORC® cabling.(r=3 mm, T=100 MPa, $2w$=4 mm, t=0.096 mm, α=45º).

Then the FEM results are compared with the theoretical results and verified by experimental winding tests. A test platform, as shown in Fig 3, is designed and produced to verify the theoretical and numerical simulations. Fig 4 compares the relaxation offset angle and relaxation offset distance under different winding pre-tension force through theoretical calculations, numerical simulations and experimental tests.

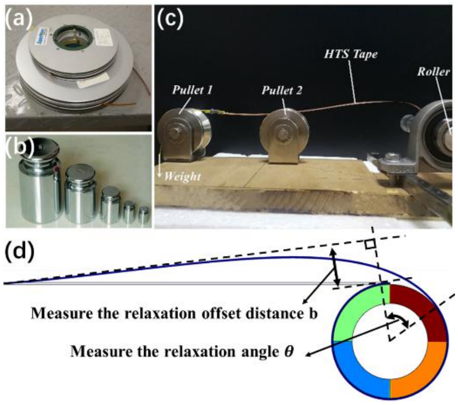

Fig 3: (a) The REBCO tapes produced by SuperPower Inc. (b) The used weights. (c) Relaxation effect test. (d) Schematic diagram of measurement method.

The tape used in the test is SCS4050 (4 mm width and 50 μm substrate thickness), which is provided by SuperPower Inc. The experimental test is performed by hanging different weights (50, 100, 200, 300, 500, 700, 900, 1000, 1500, 2000, 2500, 3000 and 4000 g) acting as the winding pre-tension force, and then slowly rotating the aluminium roller (r=10 mm). The measured result shows that as the winding pre-tension force increases, the Relaxation effect becomes weaker. The results obtained from the theoretical calculations, numerical simulations and winding tests are consistent. However, the numerical model is smaller than the theoretical calculation result and closer to the test data because of the plasticity.

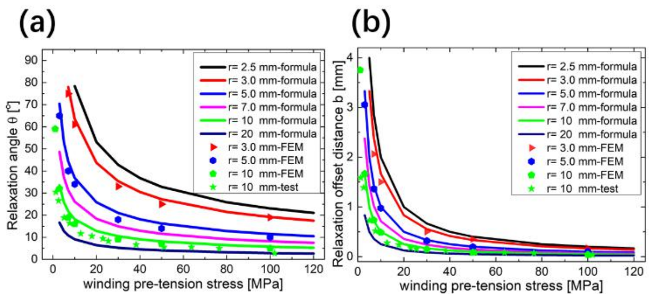

Fig 4: (a) Relaxation angle θ. (b) Relaxation offset distance b with different winding pre-tension stress.

B. *Tension process of CORC® cables.*

After the cabling process, the CORC® cables or wires will be in further processing stages, such as stretching, bending, and winding. The HTS tapes in the cables will be deformed by interlayer interaction, resulting in possible performance degradation. The contact behaviour, both the tape-to-tape contact and the tape-to-core contact in cables and coils, are more complex. The study of this contact behaviour not only helps in understanding the mechanics of the cabling process but also provides the basis for studying the current distribution in cables and coils.

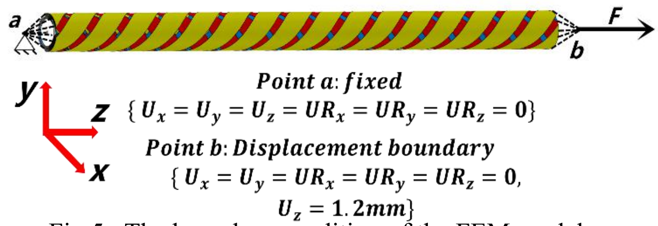

Fig 5. The boundary condition of the FEM model.

In order to analyze the contact behaviour of CORC® wires under axial tension, a three-dimensional numerical model having 30 tapes arranged in 12 layers is developed, as shown in Fig 5. A simple theoretical model can estimate the tape strain, the normal contact and friction forces during tensile loading, which helps to understand the layer interactions.

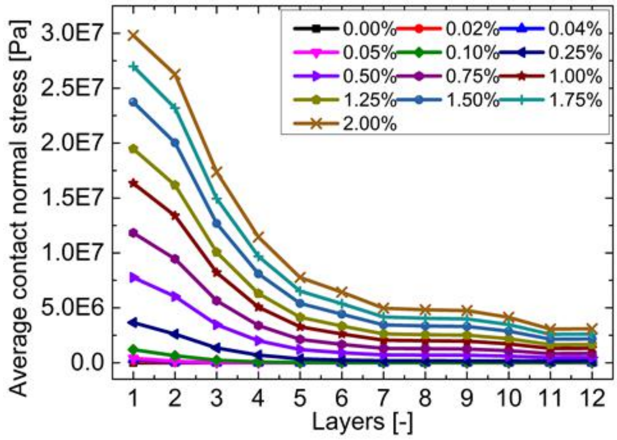

Fig 6. The average normal contact stress of each tape in a 12 layer CORC® wire under different tensile axial strain. (n=12, D=2.58 mm, α=45º &135º, L=60 mm).

The FEM results show the normal contact stress and the distribution of the REBCO strain for each layer under a total tensile strain of 0.5, 1.0, 1.5, and 2.0%. (The average normal contact force of each layer is shown in Fig 6). Firstly, the normal contact stress of each layer increases as the tensile strain increases. The inner layer is subjected to more normal contact pressure than the outer layer, and the innermost layer is the largest. This is because when stretching the CORC® wire, the innermost layer withstands the cumulative sum of all the layers above it.