Axial and transverse load FEM analysis of CORC® cables and wires

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***Abstract*— Multilayered CORC® wires can carry very high currents in background magnetic fields up to 20 T. Mechanical stresses during operation can result in irreversible degradation in the CORC® wires/cables' performance. Different mechanical loads acting on CORC® cable during production, winding, assembly, and electromagnetic operation are bending, axial and transverse loads. The tape's helical shape around the central core allows tapes to experience only a fraction of the total axial strain applied to the entire cable in the case of tensile loads. The winding angle is the main cabling parameter that influences the tensile strain limit of the CORC® cable. The radial contraction of the tape depends on Poisson's ratio of the central core and winding angle. An analytical model is proposed to estimate the tensile strain in CORC® wires and cables. With optimized cabling parameters, the irreversible strain limit of CORC® cables and wires can be as high as 7%, which is 10 to 12 times higher than the irreversible strain limit of single REBCO tapes. The major mechanical stress in fusion and detector magnets in operation is transverse compressive stress. The transverse stress tolerance of the CORC® cables and wires depends mainly on the gap spacing between layers, uniformity, and thickness of the copper layer in REBCO tape, core material, and surrounding material's hardness. A detailed finite element model is developed to study the effect of both tensile and transverse load in CORC® cables and then compared against experimental data.**

Keywords—CORC®, Finite Element Modeling, REBCO tape, HTS cables, tensile load, transverse load

I. FINITE ELEMENT MODEL FOR MECHANICAL LOADS ON CORC® CABLE

A detailed finite element model is created in ABAQUS software and validated with multilayer CORC® cable experiments. Before applying mechanical loads, two steps are the tape production process and tape winding around the core. The tape's production process involves the MOCVD process in which a thin REBCO layer is deposited on the Hastelloy substrate at 1020 K, then cooled to 350 K to deposit copper layers on top and bottom of the tape. After this, the tape is cooled to room temperature. The tape is modeled with multilayered shell elements due to the thin layer nature. The tape layers experience thermal strain due to the difference in coefficient of thermal expansion between matrix materials. The final shape of the tape is spherical. The tape is then wound over a cylindrical core, usually copper or steel. Then the whole CORC® cable or wire is cooled down to liquid nitrogen temperature.

A. Axial load

Figure 1 shows the boundary condition for the axial load on the CORC® cable. The cable's total length is 60 mm, and the grip length is 5 mm on both ends of the cable. The tensile load is applied to the grips on both ends of the cable.

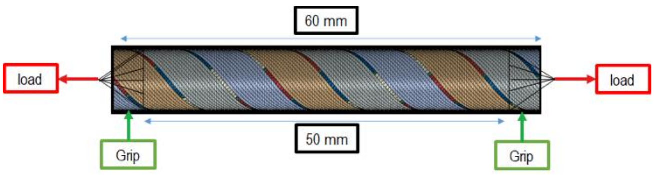

Figure 1. The boundary condition for the axial load applied to the CORC® cable.

Figure 2 shows the strain contour in the REBCO layer when the applied tensile strain exceeds the cable's critical strain limit. The grey area in Figure 2 indicates the damaged zones where the local strain exceeds the intrinsic critical strain limit of 0.45%.

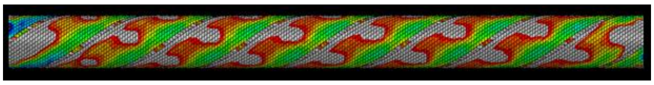

Figure 2 - Strain profile on the REBCO layer when the axial load is applied to the CORC® cable.

The main two factors that influence CORC® cables/wire's axial load performance are winding angle and poisons ratio. The influence of these parameters can be visualized by analytical equations, as shown in Figure 3. The z-axis corresponds to the axial strain factor. The axial strain factor is defined as the ratio of tape strain to cable strain. An optimized cable should have an axial strain factor close to zero. This can be achieved using winding angles near 30^0 and selecting a core material with a higher poisons ratio. For tapes with smaller widths, it might be required to maintain a suitable gap between twist pitches. The irreversible damage for cables with zero axial strain factor can only occur near the cable terminations.

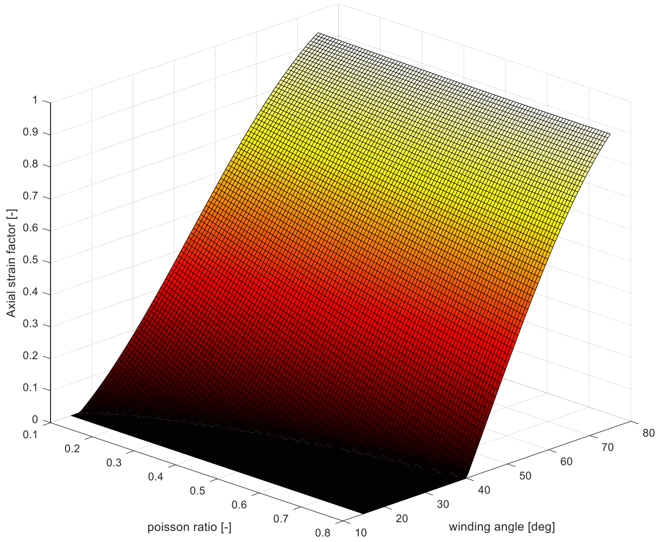

Figure 3 - Axial strain factor for various combinations of Poisson’s ratio and winding angle.

The results of the F.E. model are compared with experiments conducted by Advanced Conductor Technologies on two multilayered cables. The cables have 12 tapes in 6 layers in various winding angles. The result comparison indicates that the FEM model can successfully predict the axial load behavior of CORC® cables.

B. *Transverse loads*

The CORC® cable is pressed between two rigid plates to apply transverse load. One plate is fixed, and the other one is moved towards the cable. Since the tape is modeled as multilayer shell elements, the effect of ‘dog boning’ or variation in copper layer thickness is not considered. The rotational degree of freedom for the CORC® cable axis is constrained. Figure 4 shows the used boundary conditions for applying transverse load.

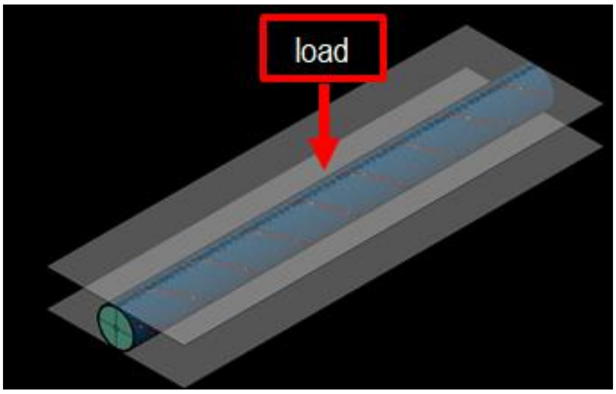

Figure 4 - Boundary conditions as used for transverse load on CORC® cables.

Figure 5 shows the strain contour in a REBCO layer of the CORC® cable subjected to a transverse load. The grey areas indicate that the tensile strain exceeds the intrinsic critical strain limit of 0.45% in certain areas of the tape above a critical transverse pressure.

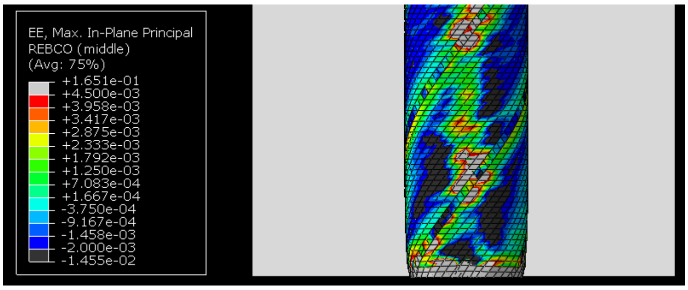

Figure 5 - Axial strain contour in the REBCO layer of the CORC® cable subjected to a transverse load.

Figure 6 shows the boundary condition for CORC® CICC with 8 CORC® cables around a central core. The transverse load in CORC® CICC can be analyzed similarly to the case in Figure 4 but by pressing the CORC® cable between two inclined plates. The inclination angle depends upon the number of CORC® cables around the central core of the CICC.

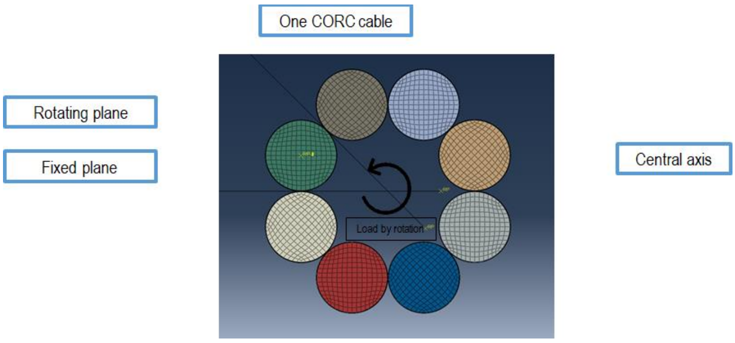

Figure 6 - The boundary condition for CORC® CICC with 8 CORC® cables around a central core.