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Multi-scale 3D modelling of a DEMO prototype cable from strand to full-size conductor based on X-ray tomography and image analysis

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The design of a superconducting magnet system of a fusion reactor candidate is usually based on the Cable-in Conduit Conductor (CICC) concept. CICC consist of complex structures with several hundreds of highly packed, multistage twisted superconductor and copper strands, cooling structures – all wrapped in thin steel foils and jacketed in relatively thick stainless-steel pipes. As recently demonstrated, such complex morphology can be captured by fully 3D X-ray tomography.
One of the three alternative winding pack (WP) options for the toroidal field coils of the European DEMO superconducting magnet system as proposed by the Italian ENEA, features a layer-wound WP design adopting a wind-and-react conductor with high aspect ratio rectangular cross section.
A multi-physics modelling requiring high accuracy from the strand to the full-size conductor scale was tested on two X-ray tomography systems. For the microstructural integrity analysis of the internal tin one mm diameter Nb3Sn strand, manufactured by Western Superconducting Technologies, a microtomograph with ~1 μm feature recognition was used. For the full-size conductor (66x25 mm2 internal dimensions) a high energy (> 300 kVp) microtomograph with voxel resolution of ~20 μm was employed. Voids and/or geometrical imperfections were detected, accurately pin-pointed and locally investigated at high resolution before and after heat treatment. Dimensional measurements on the 3D internal structure of the strand showed the small dimensional changes of the strand after the heat treatment. A significant result was the determination of the twist-pitch factor in a purely non-invasive way. The 3D reconstructions of the CICC cables were used to verify the cabling and compaction processes as well as the structural integrity of the strands, wrapping foils and spiral cooling structures. Also, 3D reconstruction of strand trajectories provided a strong input for a multi-physical modelling/interpretation of mechanical–electrical properties of CICC in cryogenic–electromagnetic environments.

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