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Electromagnetic Analysis of a ITER superconducting coil Using Three-Dimensional Integral Formulation

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ABSTRACT

The numerical analysis of ITER superconducting coils has to face several issues. For instance, the cable-in-conduit conductor (CICC) forming the coil has an intrinsic three-dimensional (3-D) geometry. Indeed, they are made of superconducting elements twisted around a central cooling channel and surrounded by a steel jacket. This complicated geometry is then folded to form the coil and different part of it are possibly connected together using resistive joints. Then, the presence of peculiar electromagnetic phenomena, such as the self-field effect on the resistive transition of full-size CICC, cannot be easily included in mono-dimensional (1-D) distributed electric parameters approaches present in the literature (e.g., [1]). So, when peculiar behaviours induced by electrical transients and self magnetic fields have to be described, a detailed and self-consistent 3-D modelling is needed.

To do this, we use a 3-D integral formulation of magneto-quasistatic Maxwell's equations in terms of edge elements shape functions [2-3]. In this model, the superconductors are described by a power law, while the introduction of some voltage and current driven equipotential electrodes allows i) to feed the cable with a desired transport current, ii) to measure the voltage drop across suitable cable lengths, identified by a pair of electrodes. In this work, we discuss the coupling of the 3-D electromagnetic model to a simple set of equations for the evaluation of the temperature evolution. This aspect is relevant especially for the analysis of the resistive transition in CICCs.

The numerical formulation is such that the whole model can be seen as a generalization of a 1-D distributed electric parameters approach [1]. Its main features include suitable surface resistivities simulating electric contacts among different parts of the cable, voltage drop measurement electrodes and the self consistently computed magnetic field of the currents flowing in the cable. Integral formulations require the storage of matrices of size scaling as n^2 (n being the number of discrete unknowns), and their inversion with computational times of the order of n^3. To make such methods convenient for large-scale problems of practical interest, such as the non linear 3-D analysis ITER Poloidal Field Central Insert (PFCI) coil (a preliminary mesh is depicted in Figure 1, where a detail of the current distribution inside the resistive joint is also shown), some so-called fast techniques can be used. We implemented an algorithm based on the Singular Value Decomposition (SVD) [4] of the blocks of the dynamical matrix describing the

interactions among the current densities flowing into well separated parts of the mesh

In this work, we will present the application of the model to the case of the PFCI coil and, preliminarily, to its short sample: the PFIS CICC (Poloidal Field Insert Sample). For the latter case, in Figure 2 we show a preliminary analysis of a resistive transition (i.e. a voltage response to a current ramp) compared with experimental results available in the CRPP Sultan Facility database (Villigen-PSI, Switzerland).

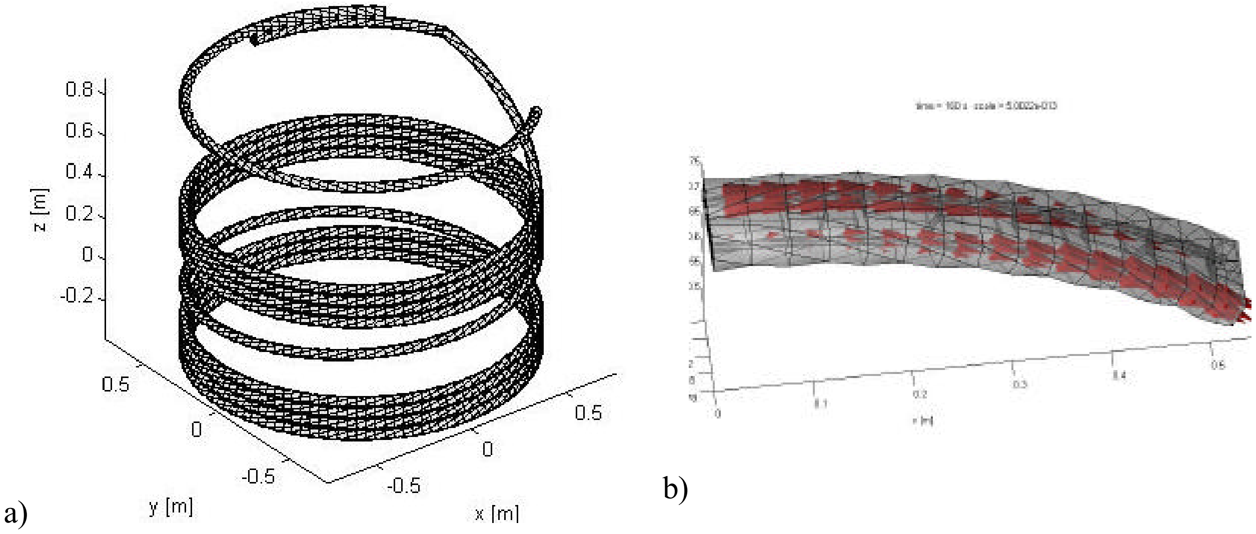

Fig. 1. a) Part of the mesh of PFCI: 14100 volume elements, 14112 surface elements, 21161 nodes. b) distribution of current density inside the resistive joint.

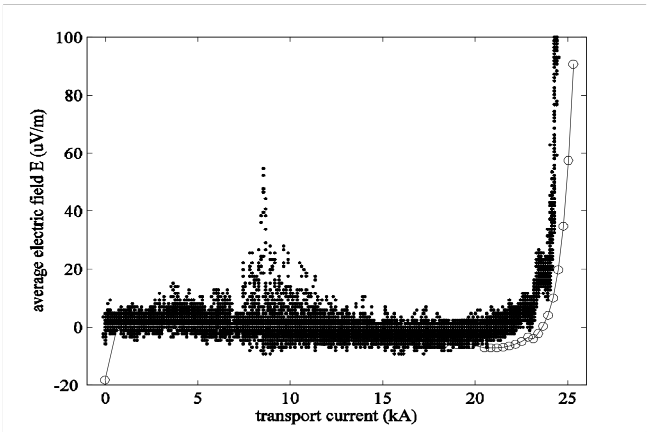

Fig. 2. PFIS response (E-I characteristic) for PCD020406 case including the temperature model

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