Simulation and Evaluation of the Superconducting Coils by Employing FEM

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Abstract: ***Many models have been proposed to assess the critical state of superconductors, and the analytical models used for fundamental geometries have been covered in prior discussions. However, numerical models must be developed to solve the complex geometries. Maxwell's equations and the E-J power law are commonly solved using numerical models (2D or 3D) that employ finite element or finite difference approaches. Finite element techniques are commonly used to solve partial differential equations (PDEs). Many researchers, notably T-, have thoroughly investigated these models in the past (based on the present vector potential T). These formulations (with same concepts) can be used to describe Maxwell's equations; however, the equivalent PDE results may differ. Since H formulations are the new work also makes use of this numerical technique, and the Article provides a detailed introduction to it.***

Keywords: Superconducting, AC losses, SMES, Smart materials

1. Introduction

Type-II superconductors have been shown to acquire resistance in the majority of electric power applications, usually at low frequencies, due to flux flow and flux creep. A greater magnetic field allows Type-II superconductors to transport more current. However, the formation of an electric field can result in losses in type II superconductors. Normal conductors will be replaced by next-generation superconductors since they produce significantly less loss than the latter. Before they can be employed in practical applications, superconductors must have a high critical current and be affordable in cost. Because superconducting devices operate at extremely low temperatures, it is important to consider economic issues. (almost at 77 K temperature). Furthermore, because the cryogenic unit must balance this heating load, heat generated as a result of AC losses increases the system's overall cost. Financial constraints like as material cost, energy cost, cryogenic unit cost, maintenance cost, and system reliability must be considered before incorporating superconductors into power devices. AC losses are observed to be less in superconducting systems than in ordinary systems because the resistance of a superconductor is almost nonexistent compared to a regular conductor. To efficiently remove the heat load from the system while maintaining superconductivity, the AC losses must be calculated correctly. There are two methods of cooling: convection cooling and conduction cooling. The coolant evaporation can be utilised to dissipate heat in convective cooling (helium and nitrogen). In contrast, a cryocooler is used in conduction cooling to maintain the system temperature constant. The full strategy for quenching superconducting tape was presented in. Because different systems have different time-varying currents or magnetic fields, the AC losses for each electrical power use must be estimated. There are two ways to calculate AC losses: magnetization loss and transport current loss. Only current losses were considered in this analysis.

2. Assumptions

1) A 2D model was employed for the study.
2) Analysis was performed on a single pancake coil.
3) To save processing time, a homogenised domain was employed rather than a multi-turned coil.
4) The turns are believed to be a bundle of parallel conductors, including both normal and superconducting materials.
5) External fields are not taken into consideration.

a) H-formulation modelling

When discrete currents are applied to distinct conductors utilising integral limitations, the external and self-fields are not segregated in any way. When zeroth-order edge elements are used to discretize the domain, H formulations enable high levels of accuracy while remaining straightforward to implement. The next section provides a thorough analysis of triangular and rectangular edge elements. Furthermore, thin rectangular domains were meshed with structured meshes. Its cross-section, made up of a bundle of parallel superconducting and normal conducting domains, can be used to simulate stacked tapes or coils. The Dirichlet boundary condition can be used to enforce the end-coupled transport current at the domain border. A barrier can be placed. 8–10 times the conductor bundle's maximum cross-sectional diameter away. Contrarily, Dirichlet boundary When the current is known, the condition cannot be utilised alone in a general scenario and must be applied to each conductor individually. One integral constraint per conductor can ensure the transport current needed for a cluster of nc parallel superconductors carrying a specific current.

b) H-formulations in Cartesian Coordinates

In the 2D Cartesian coordinate system, the tape is supposed to have an infinitely long rectangular cross-section wx d, and the space is assumed to be infinite in the z direction. The current density J flows only in the z direction, while magnetic flux is localized in the x-y plane. The rectangular tape schematic is displayed incorrectly! No such source was discovered.

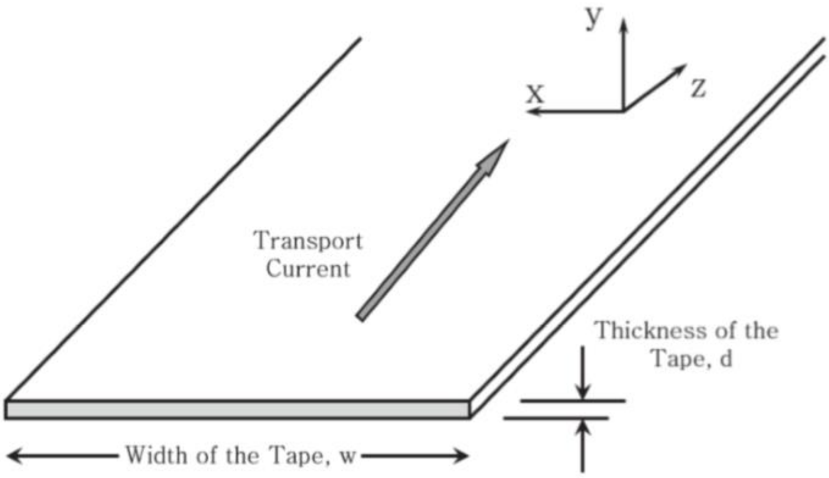

Figure 1: Schematic of the High Temperature Superconducting tape used for FEM model

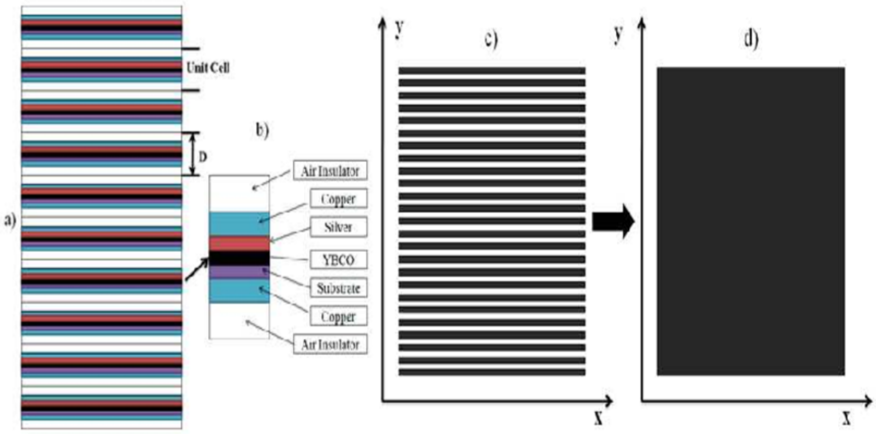

Figure 2: Computational Domain for the numerical model (a) Stacked HTS tapes, (b) Detailed view of unit cell, (c) Actual arrangement of the tapes and (d) Homogenized domain

c) Value Samples

Cu cover height (each side) 20e-6 m
Air gap and insulator height 2e-4 m
Ag cover height 4e-6 m
Substrate height 50e-6 m
HTS layer height 1e-6 m
Tape height 1e-4 m
Tape width 12e-3 m
Number of turns on pancake 108 n 30
Resistivity of Air 1 m*V/A
Resistivity of Ag 2.7e-9 m*V/A
Resistivity of Cu 1.97e-9 m*V/A
Resistivity of substrate 1.25e-9 m*V/A
Frequency of transport current 50 Hz
Critical Current Density, Jc 2.8E10 A/m2

d) Edge Elements and its Significance

Finite element methods are frequently employed to solve severe PDEs, while edge elements are commonly utilised to model curl compliant fields. Rectangular and triangular elements have been used to analyse AC losses. These components help to reduce the amount of compute required to address the issue.

3. Results and Discussion

The computational scheme was validated using the H-formulation at 77 K, which reproduced both the instantaneous and average AC losses. The authors tested 16 tapes, 32 tapes, and 64 tapes at a frequency of 50 Hz to determine the AC losses for coated conductors used in large-scale applications. The operational currents chosen for the experiment were 50 A, 60 A, and 70 A, and the critical current of the 4 mm wide tape used is 99.227 A. Table 1 lists the factors involved in their analysis, which takes into consideration local field effects. Computational analysis was performed on 32 stacked tapes that conveyed 60 A of electricity at a frequency of 50 Hz. The results obtained from the analysis has been plotted in Figure 3

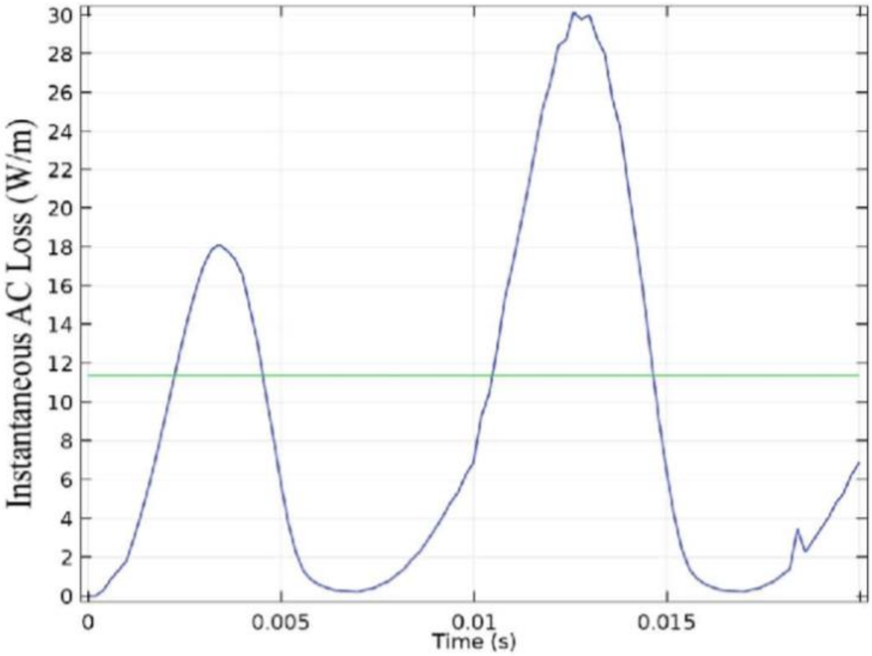

Figure 3: Instantaneous Losses Plot using present model

The curve whose coefficients are presented in Table 5-4 has been fitted using piecewise interpolation. Figure 5-8 compares the findings of the simulated study to the results of interpolating the mapped data, demonstrating that the simulated results closely reflect the mapped data. The difference between the average AC loss for mapped data (12.47 W/m) and the simulated findings (11.4 W/m) is 9%. This variance was acceptable, and the same model was used to calculate instantaneous and average AC losses of 1 MJ SMES. Data from Table 1 was displayed in Origin 8.0 software, and curve fitting was performed, and it was discovered that one correlation fitted the data. with more accuracy which is given by:

$$Loss = a + \frac{b-a}{1+10^{(c-t)d}}$$

Table 1: Mapped data from the article

Time (ms)	Instantaneous Loss (W/m)	Time (ms)	Instantaneous Loss (W/m)
1	3.1	11	17
2	9.2	12	26.2
3	17.1	13	30
4	16.8	14	21.2
5	6	15	7
6	0.8	16	0.5
7	0.3	17	0.1
8	1	18	1
9	3.6	19	3.3
10	7	20	7

The instantaneous losses (W/m) were discovered using visual mapping on a metric scale from the graph available in their study paper, and the numbers are tabulated to validate the obtained simulation findings with the work referred to in the article.

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