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MODELLING AND ANALYSIS OF THE SUPER CONDUCTING COIL USING FEM

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Abstract: Many models have been presented to assess the critical state of the superconductors, and the analytical models utilised for basic geometries have already been covered in previous discussions. However, numerical models must be created in order to solve the complex geometries. The Maxwell's equations combined with the E-J power law are typically solved using such numerical models (2D or 3D) by employing finite element or finite difference methods. Partial differential equations are frequently solved using finite element techniques (PDEs). Many scholars, including T-, have extensively examined these models in the past (based on the current vector potential T) These formulations (with identical principles) can be used to describe Maxwell's equations, however the results of the equivalent PDEs can differ from one another. Since H-formulations are employed in the current work as well, a thorough introduction to this numerical technique is provided in the Article.

***Index Terms* – Superconducting, AC losses, SMES, Smart materials.**

I. INTRODUCTION

Type-II superconductors have been found to develop resistance in the majority of electric power applications, typically at low frequencies, as a result of flux flow and flux creep. Type-II superconductors are able to carry more current when there is a stronger magnetic field present. However, the emergence of an electric field can cause losses in type-II superconductors. Normal conductors will be replaced by next-generation superconductors since they produce far less loss than the latter. Superconductors must meet a number of characteristics before being used in practical applications, including a high critical current and a low cost. One must take into account economic factors while maintaining such low temperatures because superconducting devices operate at very low temperatures (almost at 77 K temperature). Additionally, since the cryogenic unit must balance this heating load, heat produced as a result of AC losses adds to the system's overall cost. Therefore, financial restrictions such as material cost, energy cost, cryogenic unit cost, maintenance cost, and system dependability must be taken into account before adding superconductors in the power devices. AC losses are found to be smaller in superconducting systems than in ordinary systems because the resistance of a superconductor is essentially nonexistent compared to a regular conductor. In order to efficiently remove the heat load from the system and maintain the system's superconductivity, it is crucial to calculate the AC losses properly. Convection cooling and conduction cooling are two methods for cooling. The evaporation of the coolant can be used in convective cooling to dissipate heat (helium, nitrogen). In contrast, a cryocooler is utilised in conduction cooling to keep the system's temperature constant. The comprehensive strategy for quenching superconducting tape was outlined in. . Because different systems contain distinct time-varying currents or magnetic fields, the AC losses for each electrical power use must be calculated. There are two approaches to get AC losses: magnetization loss and transport current loss. Only current losses have received consideration in this investigation.

II. ASSUMPTIONS

1. 2D model has been used for the study.
2. Analysis has been performed on single pancake coil.
3. A homogenized domain has been used instead of using multi-turned coil in order to reduce computing time.
4. The turns are assumed to be a bundle of parallel conductors which consists both normal and superconducting materials.
5. External fields are not taking into consideration.

III. H-FORMULATION MODELLING

When discrete currents have been imposed on various conductors using integral restrictions, and the external and self-fields have not been separated in any way. When zeroth-order edge elements are taken into account for the discretization of the domain, H formulations provide great levels of accuracy and are simple to execute. A thorough analysis of triangular and rectangular edge elements is offered in the following section. Furthermore, thin rectangular-shaped domains have been meshed using structured meshes. Its cross-section, which comprises of a bundle of parallel superconducting and normal conducting domains, can be used to mimic the stacked tapes or coils. The transport current that is coupled at the ends can be imposed at the domain border using the Dirichlet boundary condition. The barrier can be placed 8–10 times the conductor bundle's maximum cross-sectional diameter away. Contrarily, Dirichlet boundary condition cannot be used alone in a general scenario when current is known and must be imposed in each conductor. One integral constraint per conductor can guarantee the transport current required for a cluster of nc parallel superconductors that carry a specified current.

IV. H-FORMULATIONS IN CARTESIAN COORDINATES

In the 2D Cartesian coordinate system, the tape is assumed to have an endlessly long rectangular cross-section wx d and the space is assumed to be infinite in the z-direction. Only the z-direction of the current density J is flowing, and the x-y plane is where magnetic flux is located. The rectangular tape's schematic is displayed in Error! No such source was found.

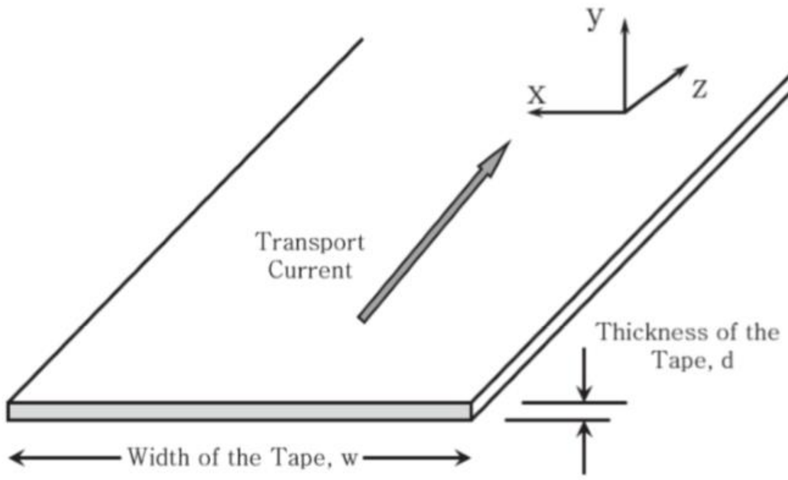

Figure 1 Schematic of the High Temperature Superconducting tape used for FEM model

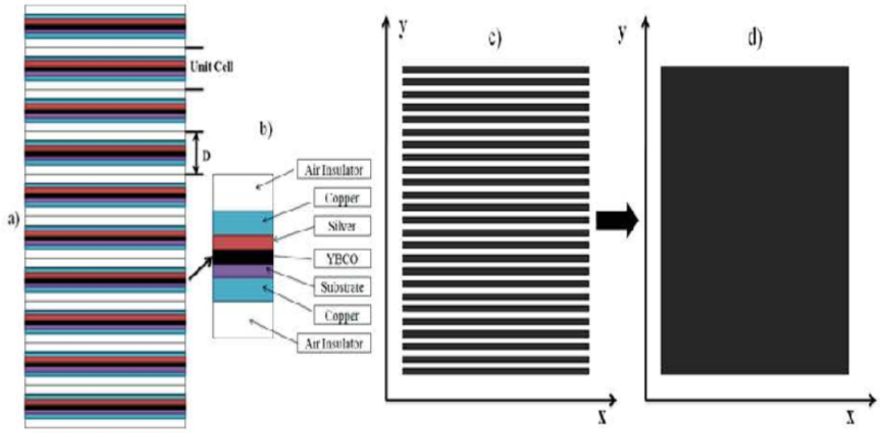

Figure 2 Computational Domain for the numerical model (a) Stacked HTS tapes, (b) Detailed view of unit cell, (c) Actual arrangement of the tapes and (d) Homogenized domain

V. 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

VI. Edge Elements and its Significance

Finite element methods are typically used to solve rigorous PDEs, and edge elements are typically used to represent curl compliant fields. Both rectangular and triangular elements have been employed to assess AC losses. These components aid in decreasing the amount of computing necessary to address the issue.

IV. RESULTS AND DISCUSSION

The H-formulation at 77 K was used to validate the computational scheme by reproducing the instantaneous and average AC losses. The authors conducted studies on 16 tapes, 32 tapes, and 64 tapes at a frequency of 50 Hz in order to evaluate the AC losses for coated conductors used in large-scale applications. The operational currents chosen for the investigation were 50 A, 60 A, and 70 A, and the critical current of the 4 mm wide tape employed is 99.227 A. The variables involved in their investigation are listed in Table 1 in order to take local field effects into account. Computational analysis has been performed for 32 stacked tapes through which 60 A current has been transported at 50 Hz frequency. The results obtained from the analysis has been plotted in Figure 3

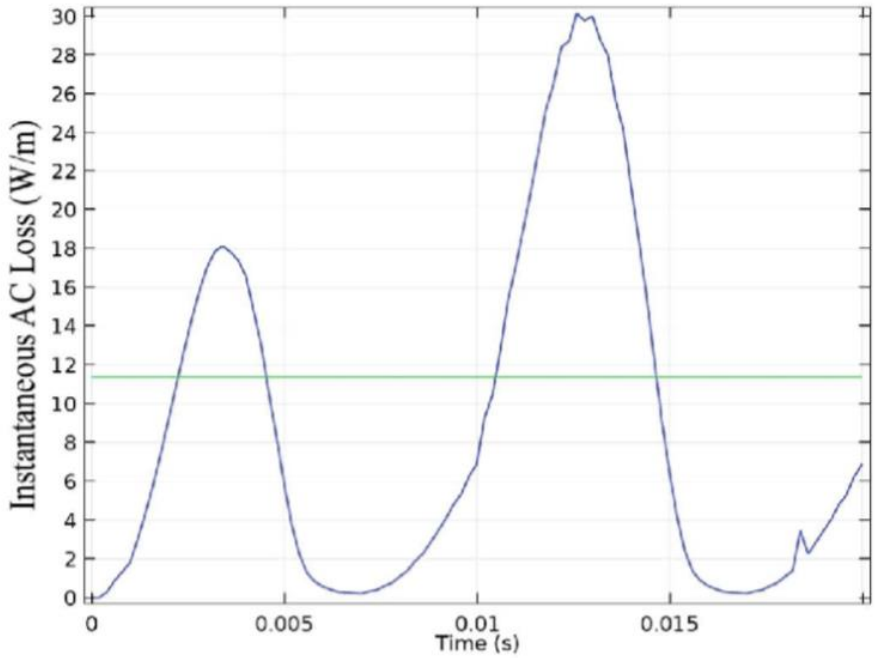

Figure 3 Instantaneous Losses Plot using present model

The curve whose coefficients are listed in Table 5-4 has been fitted using piecewise interpolation. Figure 5-8 shows the results of the simulated research and the results of interpolating the mapped data, and it can be seen that the simulated results closely resemble the mapped data. The difference between the average AC loss for mapped data, which is 12.47 W/m, and simulated findings, which is 11.4 W/m, is 9%. This variance has been accepted, and calculations of instantaneous and average AC losses of 1 MJ SMES have been made using the same created model. Data available in the Table 1 has been plotted in Origin 8.0 software and curve fitting has been done and it has been found that one correlation has 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)
0	0	-	-
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) have been detected using visual mapping utilising metric scale from the graph available in their study article whose values are tabulated in order to validate the acquired simulation findings with the work referred to in the article.

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