Development of Thermal Analysis Code for the Annular Linear Induction Pump

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1. Introduction

KAERI is developing STELLA2 sodium experiment loop. Several small capacities of electromagnetic pumps (EMP) are used for supplying sodium to the loops. During operation heat generation takes place in the coils and in the laminations due to the current flow and electrical resistance. As a result of this heat generation, the coil temperature rises, and it should be limited within permissible temperature of insulation of the copper coils. The purpose of this work is to develop a computer program which can find temperature distribution in various parts of the EMP.

2. Methods and Results

For the analysis, the finite difference technique is used to solve the governing equations. The physical problem is approximated by a system of nodes with a small volume of the domain. The finite-difference equation for a node is obtained by applying conservation of energy to a control volume about the nodal region [1].

2.1 Thermal Analysis Modeling

Because ALIP pumps are for most part axisymmetric, two-dimensional models can be set up to characterize the pump. One dimension is the length of the pump and the other is the radial distance from the center. Two-dimensional field is divided into a network of nodes.

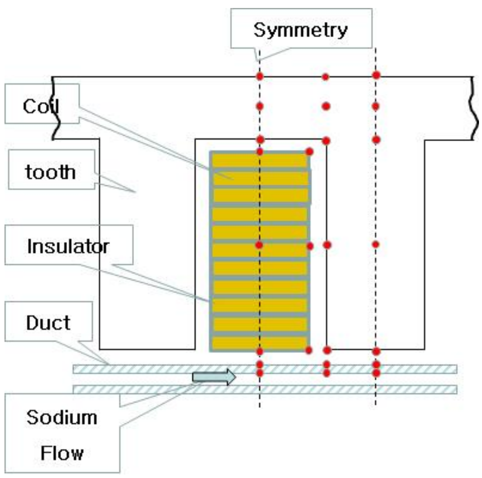

Fig. 1. Diagram of coil, insulation, lamination, duct, and nodes.

Fig. 1 is a diagram of the copper coil, ground insulation, lamination and duct used in the two-dimensional steady-state heat transfer analysis. The ground insulation surrounds the copper block.

Although there are many slots axially, only one half of the coil and on half of the lamination were considered by using the stator's symmetrical characteristics. The system of equations describing the temperature distribution is derived by applying a heat balance about each node. The nodes exchange heat by conduction, convection, and radiation. Following is an example of the steady-state energy balance equation for one of nodes on the duct with volumetric heat generation. Heat transfer from the left surface into node (2.1) is by convection and heat transfer out of node is by conduction. There is no heat transfer at symmetry surface.

$$h\cdot\left(\frac{\Delta y_1}{2}\cdot 2\pi\cdot R_1\right)\left(T_1-T_{2,1}\right)+K_{duct}\cdot\left(R_{1m}^2-R_1^2\right)\left(\frac{T_{2,2}-T_{2,1}}{\Delta y_1}\right)$$
$$+K_{duct}\cdot\left(2\pi\cdot R_{1m}\cdot\frac{\Delta y_1}{2}\right)\left(\frac{T_{3,1}-T_{2,1}}{\Delta x_1}\right)+Q_{duct}^{'''}\left(R_{1m}^2-R_1^2\right)\frac{\Delta y_1}{2}=0$$

Rearranging this equation, we obtain an equation with the effective conductance between a node and neighboring nodes as follows.

$$RES1\cdot\left(T_1-T_{2,1}\right)+RES4\cdot\left(T_{2,2}-T_{2,1}\right)+RES2\cdot\left(T_{3,1}-T_{2,1}\right)+Q_{duct}^{'''}\left(R_{1m}^2-R_1^2\right)\frac{\Delta y_1}{2}=0$$

Solving for the temperature of the node, we get,

$$\boldsymbol{T_i}=\frac{\boldsymbol{q_i}+\sum_j \boldsymbol{R_{ij}T_j}}{\boldsymbol{R_{ij}}}$$

Similar equations are derived for all the nodes in the calculation domain. The set of algebraic equations is solved by Gauss-Seidel iteration method. The iteration is terminated when a convergence criterion is satisfied, that is, an error in the temperature is less than 0.0001 C for present analysis.

For the heat conductance of the copper block in radial direction the effective thermal conductivity of the copper block, including the insulation between the coil strands, is determined from following equation under the law that the resistances are additive [2].

$$k_{eff} = \frac{\delta_{copper+insualtion}}{\frac{\delta_{copper}}{k_{copper}} + \frac{\delta_{insulation}}{k_{insulationr}}}$$

2.2 Validation

To validate the 2-D thermal analysis model, a steady state thermal analysis was performed to determine the temperature distribution in the Outer Stator Coil Assembly of the PGSFR IHTS ALIP Pump. An axial section of the assembly is shown in Fig. 2. The full pump assembly consists of several of these sections stack axially. Liquid Na at 335°C flows axially through the inner duct. Steel laminations (i.e. Tooth and Yoke) are located around the outside of the duct and are held in place and tensioned against the duct wall by the alignment and spring housing assemblies located at the outside edge of the lamination blocks. The housing assemblies are mounted to a frame that is in turn mounted to the casing of the pump. Copper coils are located inside of the steel laminations and are used to conduct electrical current in order to create the required magnetic field. As a result of the current flow, the coils are significantly heated internally by electrical resistance in the coils. All materials are steel with the exception of the copper coil and the associated electrical insulation. The assembly is surrounded by a nitrogen atmosphere. The outside casing is assumed to be held at the Na temperature of 335 °C [3].

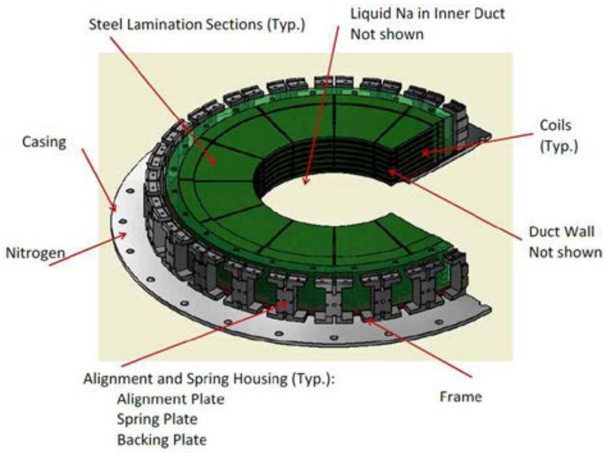

Fig. 2. Outer stator coil assembly of the PGSFR IHTS ALIP Pump.

The temperature distribution predicted by the code along the two lines in the symmetry plane are shown in Fig.3. It can be seen that the temperature drops sharply at the contact area between the lamination tooth tip and the duct wall. The temperature of the lamination changes from about 400 °C to 467 °C due to the heat generation in the lamination. The temperature of coil shows the maximum coil temperature of 528 °C. It can be seen that the 2-D predicted temperature matches well with the results of 3-D ANSYS thermal analysis model.

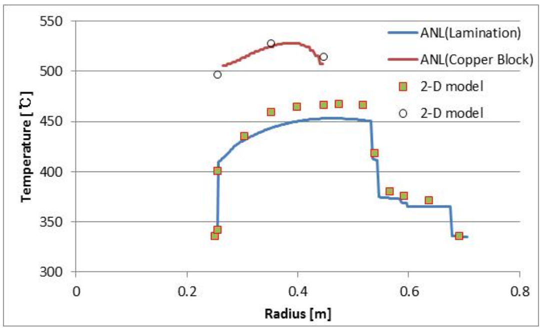

Fig. 3. Comparison of thermal analysis results from 2-D model and ANL 3-D ANSYS model.

3. Conclusions

2-D thermal analysis model has been developed. The thermal analysis results have been verified against 3-D ANSYS thermal analysis model which performed by ANL. This model is useful for predicting the temperature distribution in the coil and various part of the EMP.

ACKNOWLEDGEMENT

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