3D FEM and Lumped-Parameter Network Transient Thermal Analysis of Induction and Permanent Magnet Motors for Aerospace Applications

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Abstract. Three dimensional (3D), finite element (FE) models and original lumped-parameter networks are developed for the transient thermal analysis of a permanent magnet synchronous motor (PMSM) and an induction motor (IM) specifically designed and optimized for a demanding aerospace actuation application. A systematic comparison between the two different thermal modeling approaches is carried out using different loading conditions including mixed cycles of temperature increase and decrease.

1. Introduction

This paper concerns the thermal analysis of two actuators, a permanent magnet synchronous motor (PMSM) and an induction motor (IM), designed for inadequate convective heat transfer and short overload conditions, encountered in a demanding aerospace actuation application [1]-[4].

A surface mounted PMSM was designed and optimized for two different modes of operation. Under the normal mode of operation the torque and rotating speed are equal to 1.2 $N \cdot m$ and 180 rpm respectively. Under the extreme mode of operation, torque and rotating speed are equal to 6.0 $N \cdot m$ and 6,000 rpm respectively. High temperature, samarium cobalt permanent magnets and non-overlapping, alternate-teeth-wound, fractional slot concentrated winding configuration were used [1].

An IM was also designed for the aforementioned aerospace application. A non-overlapping winding was not the optimum choice for the IM. As a result, a conventional winding configuration was used. For the rotor bars the NEMA design class A was adopted due to the high torque capacity and efficiency at low slip frequencies [1].

2. 3D FE Thermal Transient Analysis of the IM and PMSM

A number of transient and steady state, three dimensional (3D), finite element (FE), thermal analyses for different material attributes and load characteristics of the IM and PMSM were carried out using a FE package assembled by the authors [4]. Mesh sizes of $1.0 \cdot 10^6$ to $2.0 \cdot 10^7$ first-order tetrahedral elements and a typical desktop PC were used for the analyses.

Figs. 1 and 2, show respectively the temperature distribution of the IM and PMSM running under maximum load for a late step of the transient thermal analysis. Analysis time ranges from 0.18 s to 8,233 s and the time-step ranges from 0.18 s for the first step to 5,626 s for the last step.

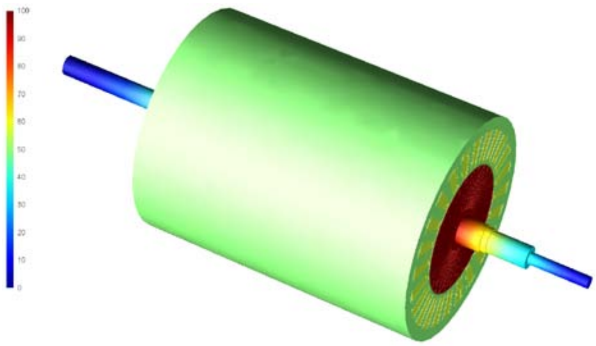

Fig. 1. IM temperature distribution at 2607 s.

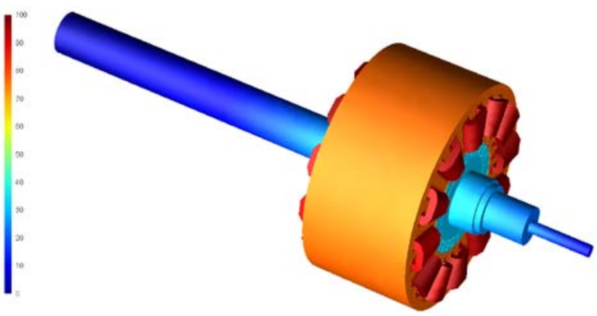

Fig. 2. PMSM temperature distribution at 2607 s.

3. Lumped-Parameter Model for Thermal Transient Analysis

Fig. 3 shows the lumped-parameter network developed for the thermal transient analysis of the two actuators. It is based on an original configuration that involves a minimum number of elements and therefore it presents a reduced computational cost in comparison with conventional lumped-parameter models [3].

The specific configuration was implemented using Matlab and the SimPowerSystems library of Simulink. The values of the parameters of the elements of the specific model were determined by analytical expressions taking into consideration the geometric and operational characteristics of the IM and PMSM, as well as the physical properties of the materials of the two actuators i.e., the stator laminated steel, the permanent magnets, the rotor bars, the winding copper, and the winding insulation material. Finally, the loading characteristics of the lumped-parameter model were set by controlling the magnitude of the current sources. The current sources in the specific model represent the winding losses and the iron losses of the stator and rotor.

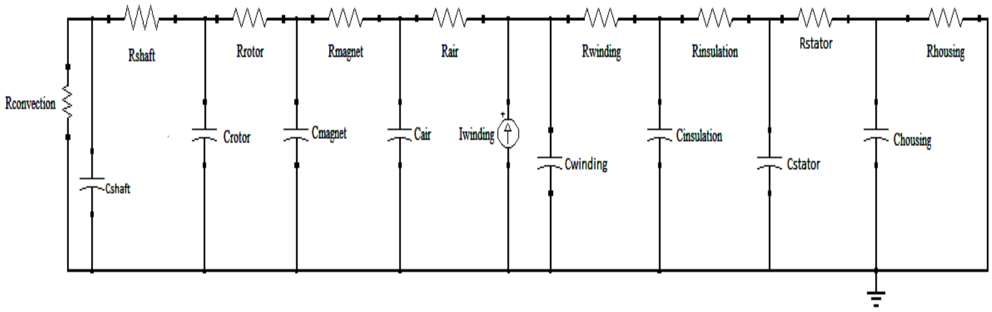

Fig. 3. Lumped-parameter model for the thermal analysis of the two aerospace actuators.

4. Results and Discussion

A number of transient thermal analyses of the IM and PMSM were carried out, using the developed 3D FE and lumped-parameter models, for different ambient temperatures and load conditions. Figs. 4, 5 show respectively a comparison of the simulated 3D FE and lumped-parameter network, temperature variation of the stator winding and rotor of the actuators.

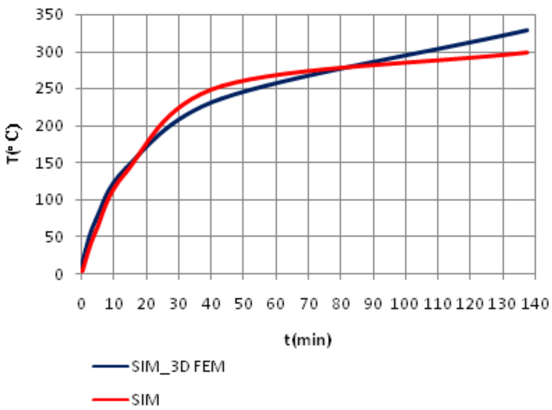

Fig. 4. Stator winding temperature variation of the actuators.

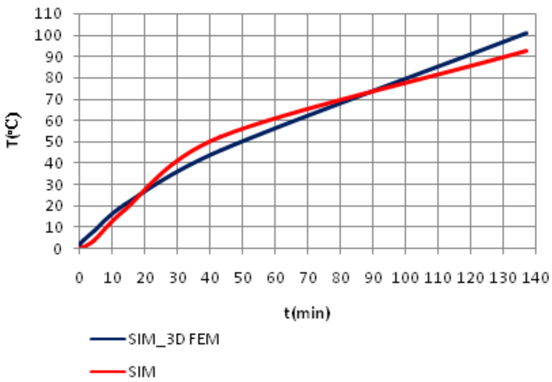

Fig. 5 Rotor temperature variation of the actuators.

5. Acknowledgment

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