AC Loss Simulation in HTS Armature Windings of A 100 kW All-HTS Motor

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***Abstract*—An all-HTS motor is a promising device that can provide more compact size and higher performance than conventional motors. However, high AC loss in the HTS armature windings requires large cryogenic system which makes all-HTS motors impractical. This work numerically studied AC loss behaviours of the HTS armature windings in a 100 kW, 1500 rpm HTS motor. The model is based on COMSOL Multiphysics and *T-A* formulation. In order to investigate the real time electromagnetic behaviours, the moving mesh and rotating machinery interface are applied in this model. Preliminary results on magnetic flux distribution in the whole motor, current density in the HTS armature windings as well the AC loss are presented.**

Keywords— HTS motor, AC loss, *T-A* formulation, moving mesh

1. Introduction

High AC loss in armature windings is one of key issues for achieving all-HTS motors [1]. As a powerful tool, FEM modelling has been widely used to study the electromagnetic behaviours in HTS motors in recent years [2–4]. In this work, a 100 kW, 1500 rpm all-HTS pump motor was numerically studied in order to investigate the loss behaviours in the armature windings.

The schematic of cross-section in this motor is shown in the figure 1. The main design parameters for this HTS motor are listed in Table 1.

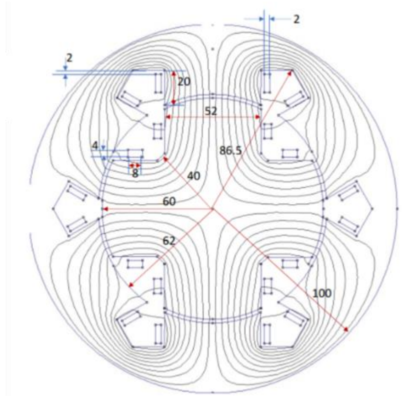

Figure 1. Schematic cross section of the 100 kW, 1500 rpm all-HTS motor

Table 1. Main parameters of the HTS motor

Parameters	Value
Output power (kW)	100
Rotating speed (rpm)	1500
Operating temperature (K)	65
Ampere-turns per armature coil (kA)	1.5
Ampere turns per field coil (kA)	4.0
Outer diameter of the motor (mm)	200
Air gap (mm)	2
Diameter of the rotor (mm)	120
I_c of the HTS wire at 65 K s.f. (A/cm)	765
Material of iron core and yoke	Silicon Steel Non-grain oriented M-36

2. Numerical modelling and results

In this motor, both field windings and armature windings are designed using REBCO conductors. However, the AC loss in the field windings is not considered. The model was simplified by only applying ***E-J*** power law and asymmetric $I_c(\theta)$ characteristics of the HTS wires in the armature windings while the current density in the field windings was set as a constant.

The asymmetric $I_c(\theta)$ characteristics of the HTS wires were from the Robinson Research Institute HTS wire data base [5].

The ***T-A*** formulation was applied to this motor model [6 – 8]. ***T*** formulation was applied to the HTS armature windings by using "Coefficient Form Boundary PDE" interface in COMSOL and ***A*** formulation was applied to whole FEM model by using "Rotating Machinery, Magnetic" interface. In order to study the electromagnetic behaviours of whole motor at a rotating condition, moving mesh was applied to the rotor part of the model.

In our current work, 14-turn double race-track coils wound with 4 mm wide REBCO wires were considered as the armature windings. The distribution of current density normalized by the local J_c in one slot at 1/4 circle is shown in figure 2.

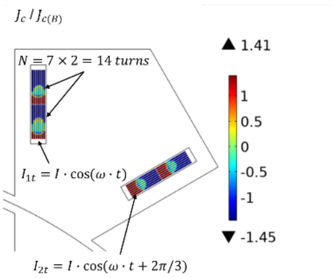

Figure 2. Distribution of normalized current density in one slot of armature windings at 1/4 circle. Each coil has $7 \times 2 = 14$ turns HTS wires.

Magnetic field distributions of the entire motor are illustrated in figure 3. Due to the iron poles yoke, HTS windings can avoid experiencing high magnetic flux density, which in turn reduces the AC loss in the HTS windings.

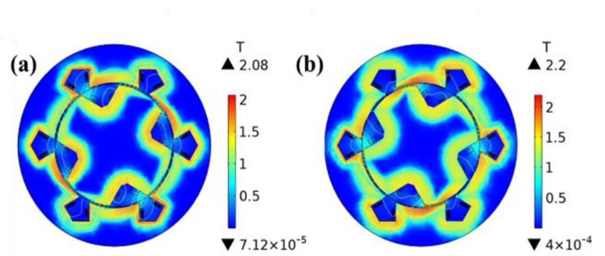

Figure 3. (a) at 1/6 and 1/3 circle, distribution of magnetic flux density norm in whole motor.

The instantaneous AC loss for all armature windings with/without operating current is shown in figure 4.

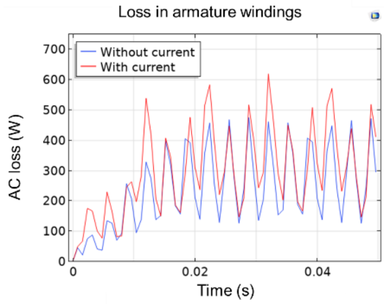

Figure 4. (a) Instantaneous loss in armature windings with/without operating current (1.5 kA ampere-turn).

The result with current is slightly greater than that without current. This implies most of AC loss in the armature windings is magnetization loss. Transport AC loss in the windings is negligible because the designed operating currents in an HTS motor is much lower than its critical current ($\frac{I_t}{I_c}$ is smaller than 0.5) for safety consideration. Various coil designs will be considered in the following works to reduce AC loss in the HTS armature coil windings.

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