AC loss simulation in HTS armature winding of a 100 kW all-HTS motor

S. You[1], S. S. Kalsi[2], M. D. Ainslie[3], R. A. Badcock[1], N. J. Long[1], Z. Jiang[1]

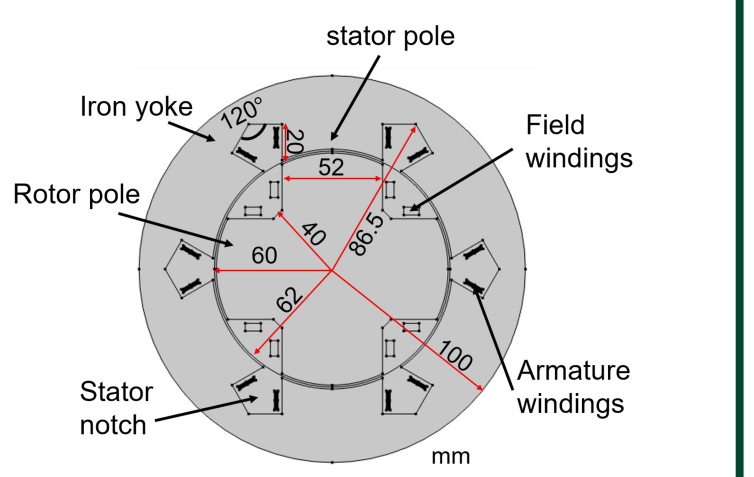
[1] Robinson Research Institute, PO Box 33436, Lower Hutt 5046, New Zealand. Email: zhenan.jiang@vuw.ac.nz
[2] Kalsi Green Power System, LLC Princeton, NJ 08540 USA
[3] Department of Engineering, University of Cambridge, Cambridge, UK

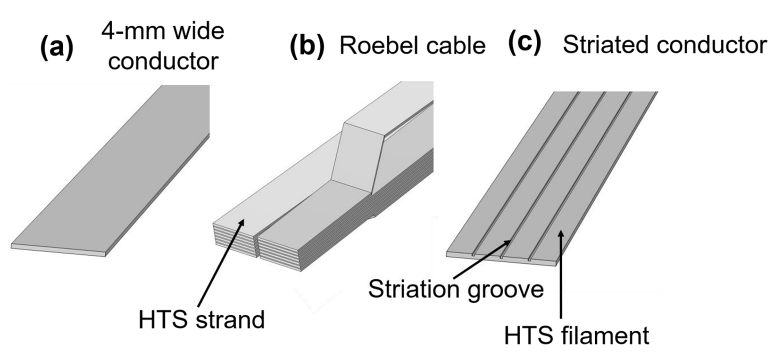
Introduction

- In an all- HTS motor, armature windings will carry AC currents under rotating magnetic fields. AC loss generated in the armature windings poses a major challenge to cooling system [1]. Methodology of AC loss reduction in the armature windings has to be developed.
- Recent years, ***T-A*** formulation [2] which offers the advantage of easier implementation in the FEM (finite element method) models and faster computing time is applied for simulating HTS motors [3]. However, previous simulation works only considered plain REBCO tapes in the armature windings.
- In this work, a 100 kW 1500 rpm all-HTS motor is designed and AC loss simulations in HTS armature windings wound with different types of HTS conductors are carried out.
- We simulated the loss behaviours in the armature winding wound with three different types of conductors. They are 4 mm-wide REBCO conductors, 14/2 (fourteen 2 mm wide strands) REBCO Roebel cables and striated REBCO conductors with four 1 mm-wide filaments.
- We simulated the AC loss at different temperatures for exploring the AC loss dependence on the operating temperature.
- AC loss simulation in the HTS armature winding wound with a SuperPower SCS4050 AP (artificial pinning) wires which exhibit strong asymmetric $I_c(B,\theta)$ characteristics is carried out to study the influence of the wire $I_c(B,\theta)$ on AC loss in the HTS armature winding under rotating magnetic fields.

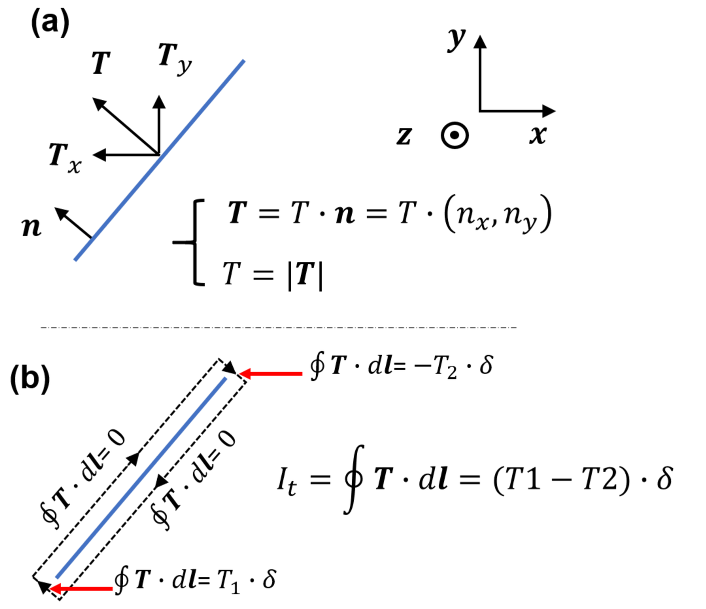
Motor design

Parameters	Value
Output power (kW)	100
Rotating speed (rpm)	1500
Operating temperature (K)	65
Self-field I_c of the HTS wire at 65 K (A/cm)	765
Ampere-turns (AC) per armature coil (kA)	1.5
Frequency of armature current (Hz)	50
Ampere-turns (DC) per field coil (kA)	4.0
Number of poles	4
Outside radius of the stator core (mm)	100
Inside radius of the stator core (mm)	62
Outside radius of the rotor core (mm)	60
Active length of the motor (mm)	300
Rotor pole width (mm)	52
Rotor pole length (mm)	24
Stator pole length (mm)	20
Stator notch width (mm)	11
Air gap (mm)	2
Radius to notch corner (mm)	86.5
Material of iron core and yoke	Silicon Steel Non-grain oriented M-36

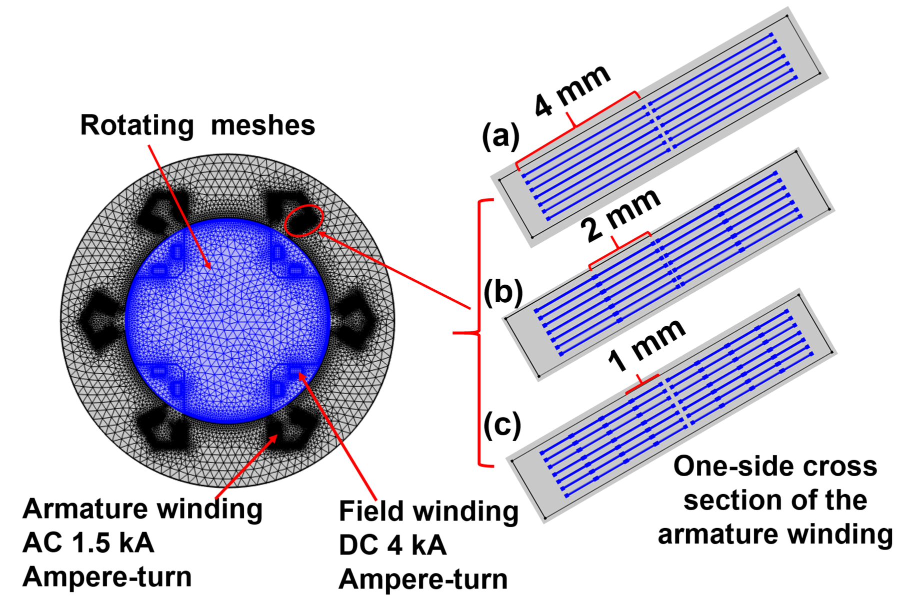




Numerical method

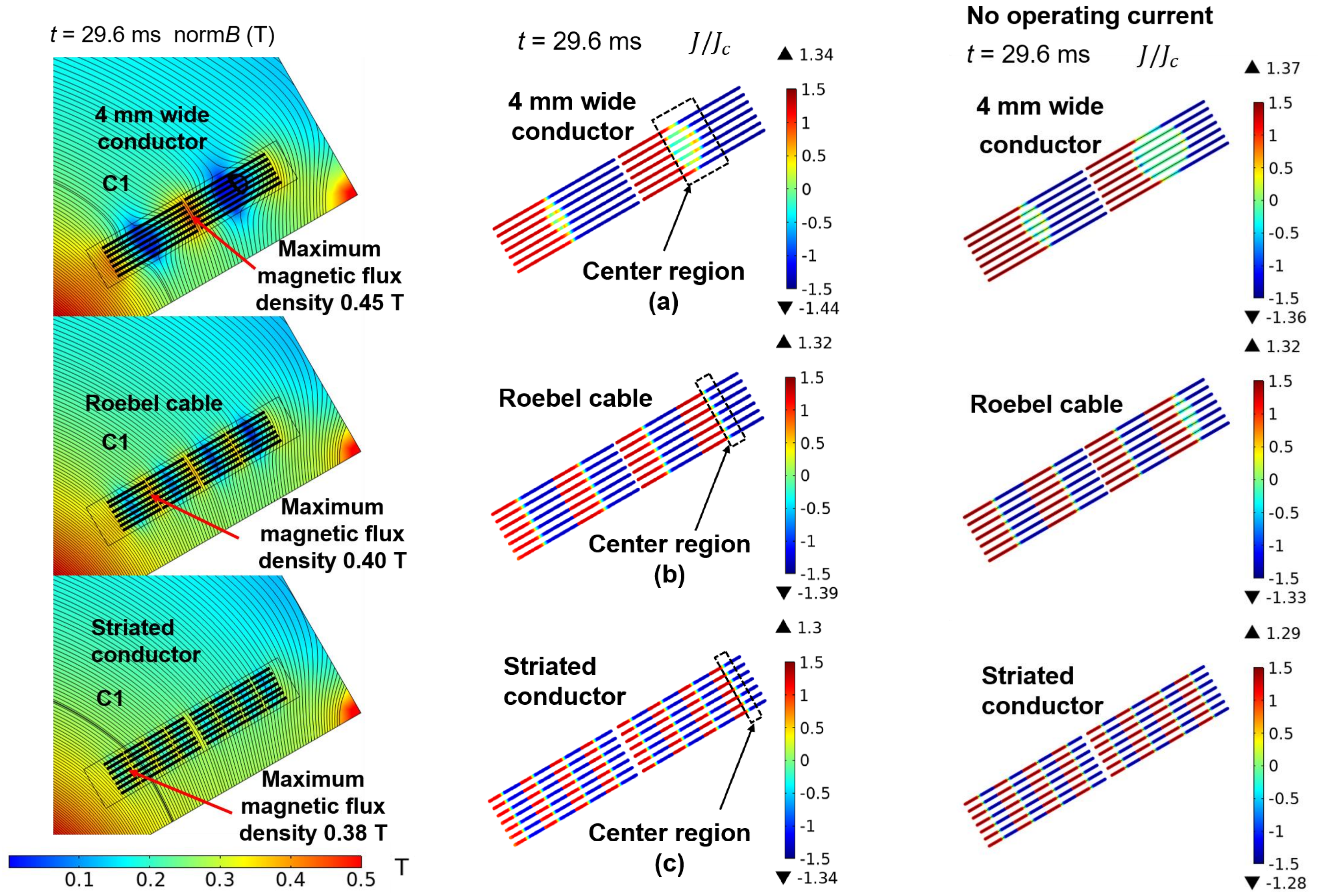


- (a) Definition of current vector potential T on the boundaries.
- (b) Boundary conditions for the applied current in the HTS tape.



- Rotating mesh is applied in the field windings and rotor.
- Cross section of one-side winding (C1) wound with three different types of conductors
- Roebel cables and striated conductors is equivalent to a stack of double racetrack coils wound with 2 mm conductors and 1 mm conductors, respectively.

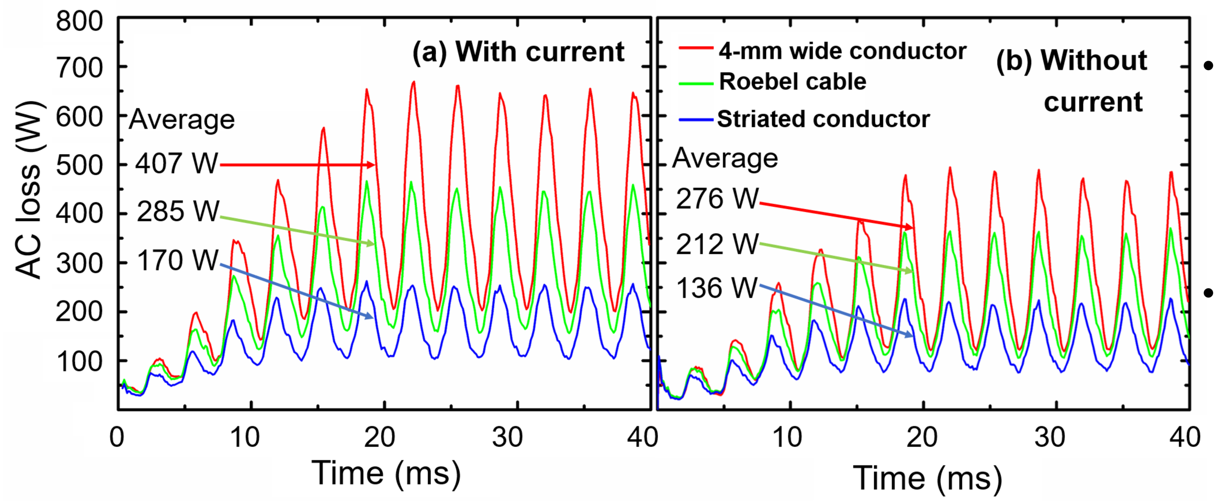
Simulation results



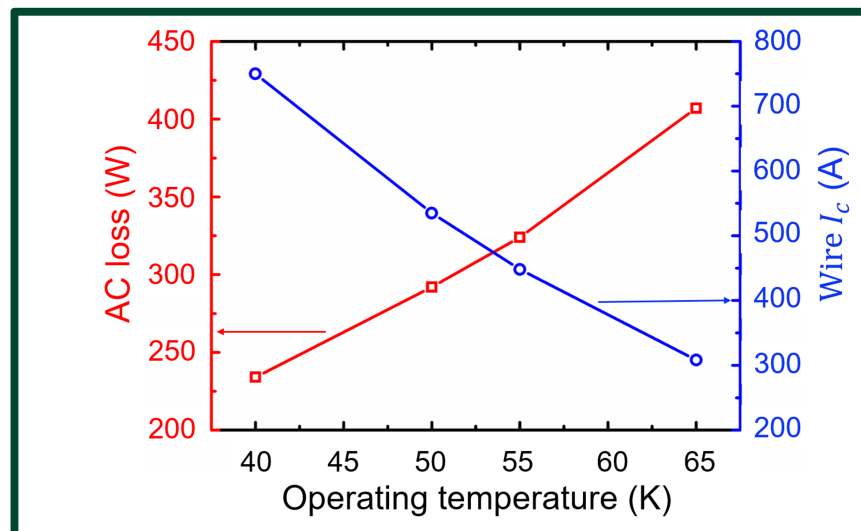
- Flux-free regions in C1 wound with 4 mm-wide conductor is due to shielding current.
- The maximum value of magnetic flux density in C1 is reduced by using Roebel cables and striated conductors.

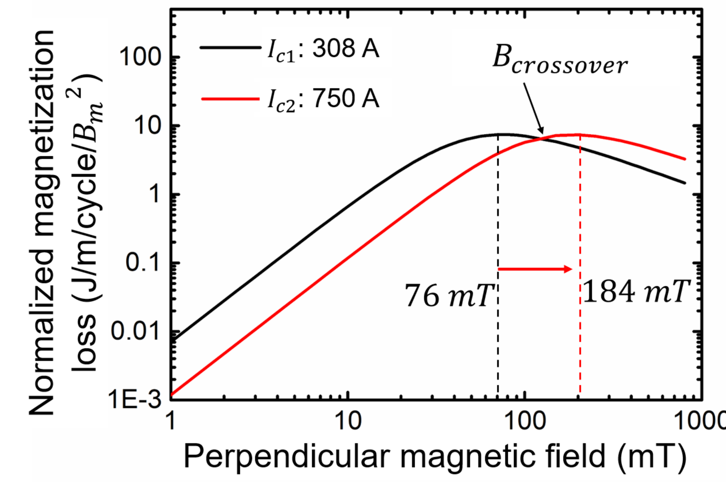
- Magnetic flux is fully penetrated in the regions where $|J/J_c|$ >1.
- The AC loss is mainly generated in these regions.
- zero current regions are corresponding to the flux-free regions.

- Normalized current density in C1 without operating current.
- This implies that magnetization loss due to shielding current caused by the rotating field dominates the total AC loss



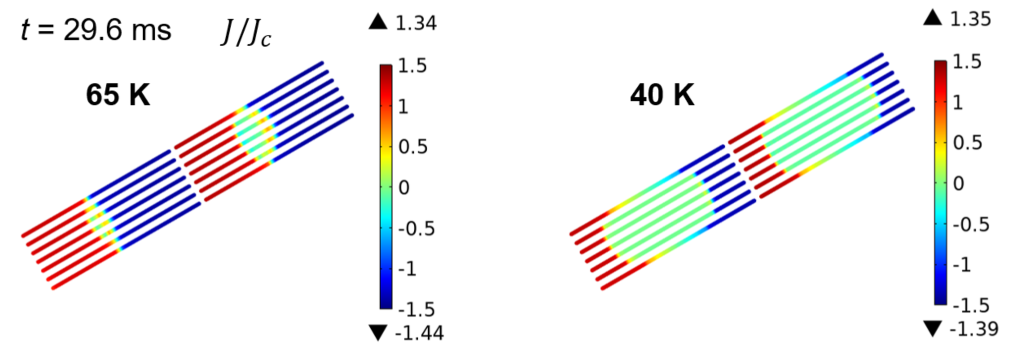
- Total AC loss in all armature windings is significantly reduced by applying Roebel cables and striated conductors
- Large magnetization loss is reduced in the armature winding wound with Roebel cables and striated conductors



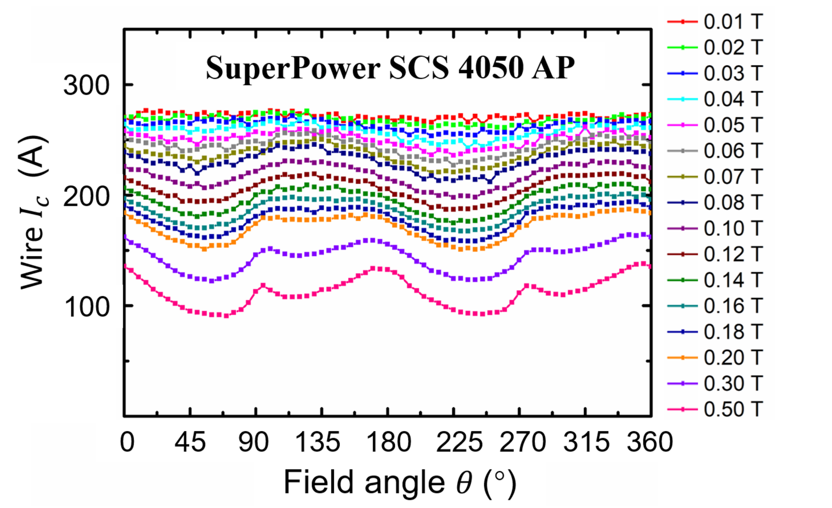


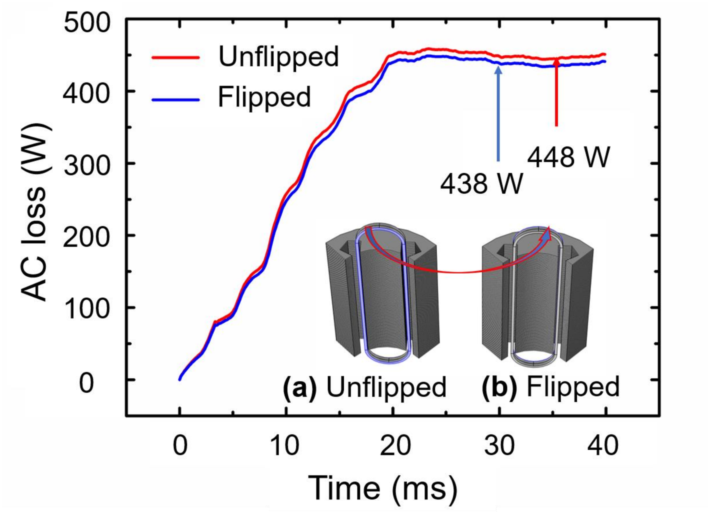
- The average AC loss in the armature winding decreases with decreasing the operating temperature.
- the self-field critical current values in the conductor increase with decreasing the operating temperature.

- The increase of the effective penetration magnetic field in high I_c conductor, i.e. the effective penetration field shifts towards higher magnetic field [4].



- We attribute the AC loss characteristics to the change of the effective penetration field in the coil windings due to the change of operating temperature.





- The measured $I_c(B,\theta)$ dependence of 4 mm wide SuperPower SCS AP conductor in the full field range (0° – 360°) at 65 K [5].
- It shows strong asymmetric $I_c(B,\theta)$ characteristics.

- 10 W loss reduction achieved by simply flipping the coil winding [5].
- This is the first numerical demonstration of AC loss reduction in a coil winding wound with asymmetric $I_c(B,\theta)$ conductor under the rotating magnetic field.

Summary

- We have numerically investigated AC loss behaviours in the armature windings of a HTS motor wound with different types of HTS conductors at 65 K using ***T-A*** formulation and rotating mesh technique.
- AC loss in the armature winding could be significantly reduced by applying the low-loss Roebel cables and striated conductors. The AC loss reduction is mainly due to reduction in magnetization loss.
- AC loss in the armature windings decreases with decreasing the operating temperature. We attribute the AC loss reduction to the increase of the effective penetration field which is proportional to the critical current.
- 2% AC loss reduction is achieved by simply flipping the armature windings, which is wound with asymmetric $I_c(B,\theta)$ HTS conductors.

Reference

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