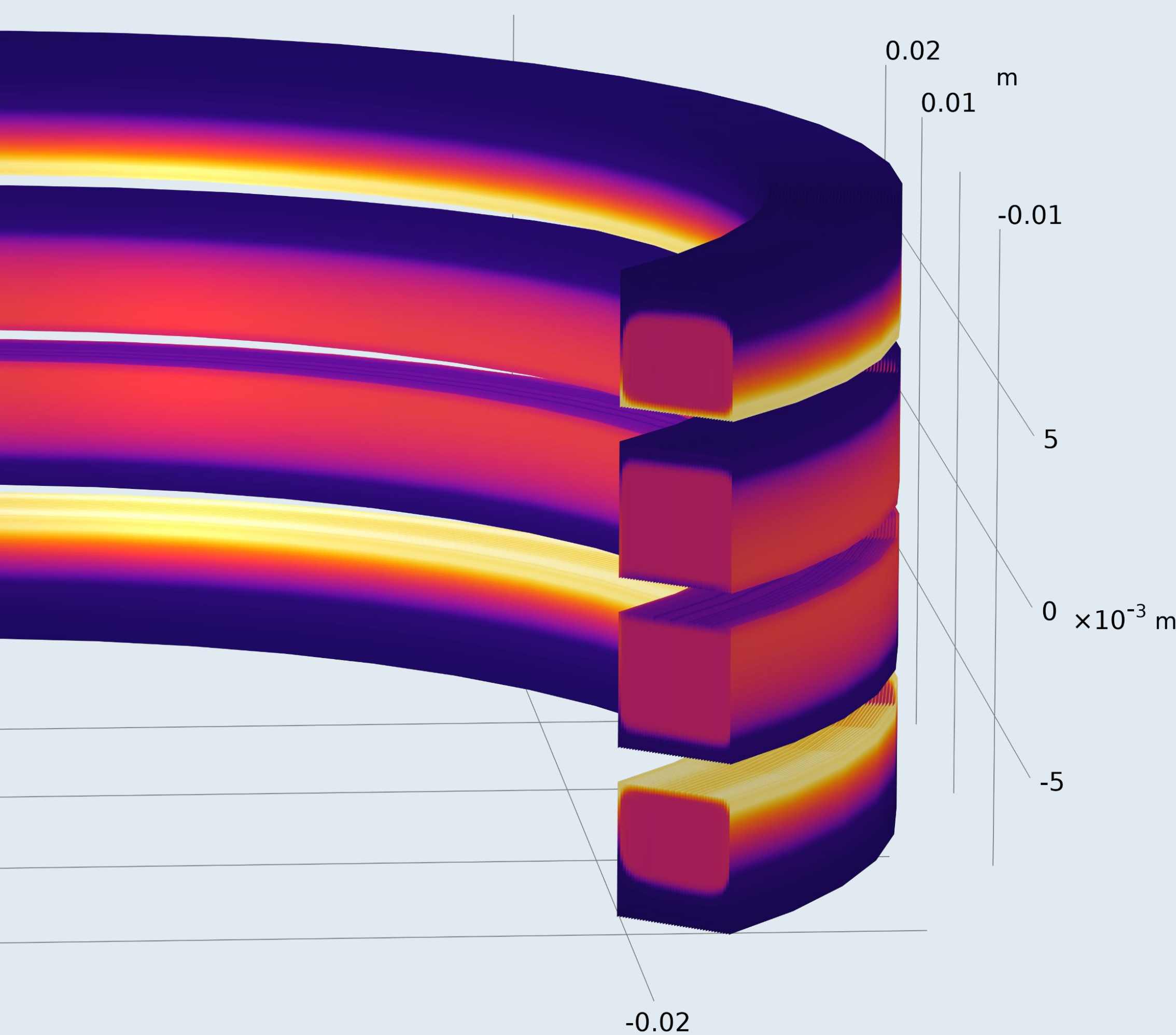




Modelling High-Temperature Superconductor REBCO magnets

High-Temperature Superconductors (HTS) show no resistance below their critical temperature when operated in DC, but this is not the case anymore when operated in AC. Transient events must be carefully modelled to estimate the Joule heating and to design the cooling system appropriately.

Tara Benkel

Atled Engineering Ltd, Abingdon, United Kingdom

Abstract

The rapid advancement of HTS *REBaCuO* ("REBCO") is enabling disruptive solutions across a wide range of sectors, including energy, medical systems, space applications, and high-field magnets.

Even in DC systems, magnets experience transient operation: they must be charged and discharged, and during these processes, HTS conductors experience losses, which need to be assessed.

COMSOL Multiphysics® has been extensively used to model HTS devices and has been verified against experimental work numerous times. Combined with its flexibility in allowing users to implement their own partial differential equations, this has made COMSOL Multiphysics® a go-to tool for assessing AC losses in HTS devices.

In this illustrative case, a magnet made of 4 pancakes wound with one insulated HTS REBCO tape is implemented in COMSOL Multiphysics® to assess its AC losses during charge.

Methodology

The magnet is made of a stack of 4 pancake coils wound with one layer of HTS tape, FIGURE 1, left. The magnet is then energised using a constant di/dt , until the tape starts transiting to its normal state, which indicates the value of the limiting critical current of the magnet.

Using symmetry, only two pancakes are modelled using a 2D axisymmetric structure, FIGURE 1, right. Different formulations of Maxwell's equations can be used to simulate HTS REBCO behaviour and compute AC losses. Here the so-called H- ϕ [1] is implemented. H-formulation is implemented on the conducting domain, where Faraday's law is solved in the following form:

$$\nabla \times (\rho \nabla \times \mathbf{H}) = -\mu_0 \frac{\partial \mathbf{H}}{\partial t}, \text{ where } \rho_{HTS} = \frac{E_c}{J_c} \left(\frac{|\mathbf{J}|}{J_c} \right)^{n-1}$$

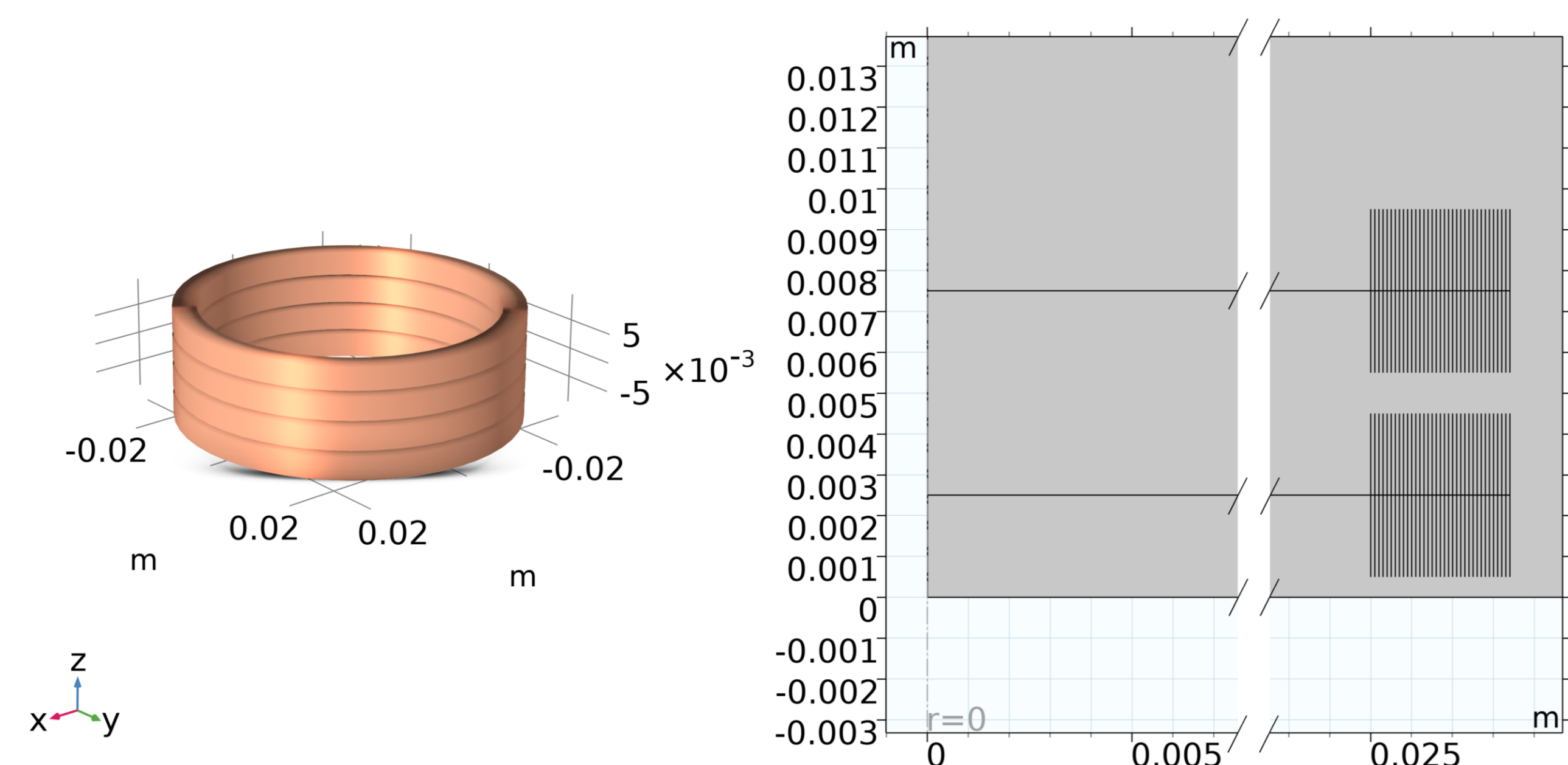


FIGURE 1. Left: illustration of the 3D geometry of the magnet made of a stack of four pancakes. Right: illustration of the two-pancake geometry using a 2D axisymmetric structure.

Results

Modelling HTS magnets is challenging; AC operation requires transient simulations and the REBCO layer is $\sim 1 \mu\text{m}$ thick, while the magnet itself may reach several metres in size. Models must then bridge multiple orders of magnitude in physical size, quickly becoming computationally intensive. In addition, REBCO performance depends not only on the temperature, but also on the local current density, magnetic field magnitude and relative angle with respect to the conductor's surface.

The ratio of current density to the critical current density of the upper two pancakes, FIGURE 2, left, shows the current penetrating the tape stack from the edges of the winding pack and part of the stack carrying no current yet. Knowing the current distribution, the spatial distribution and magnitude of AC losses can then be calculated from $\mathbf{J}$ and ρ_{HTS} .

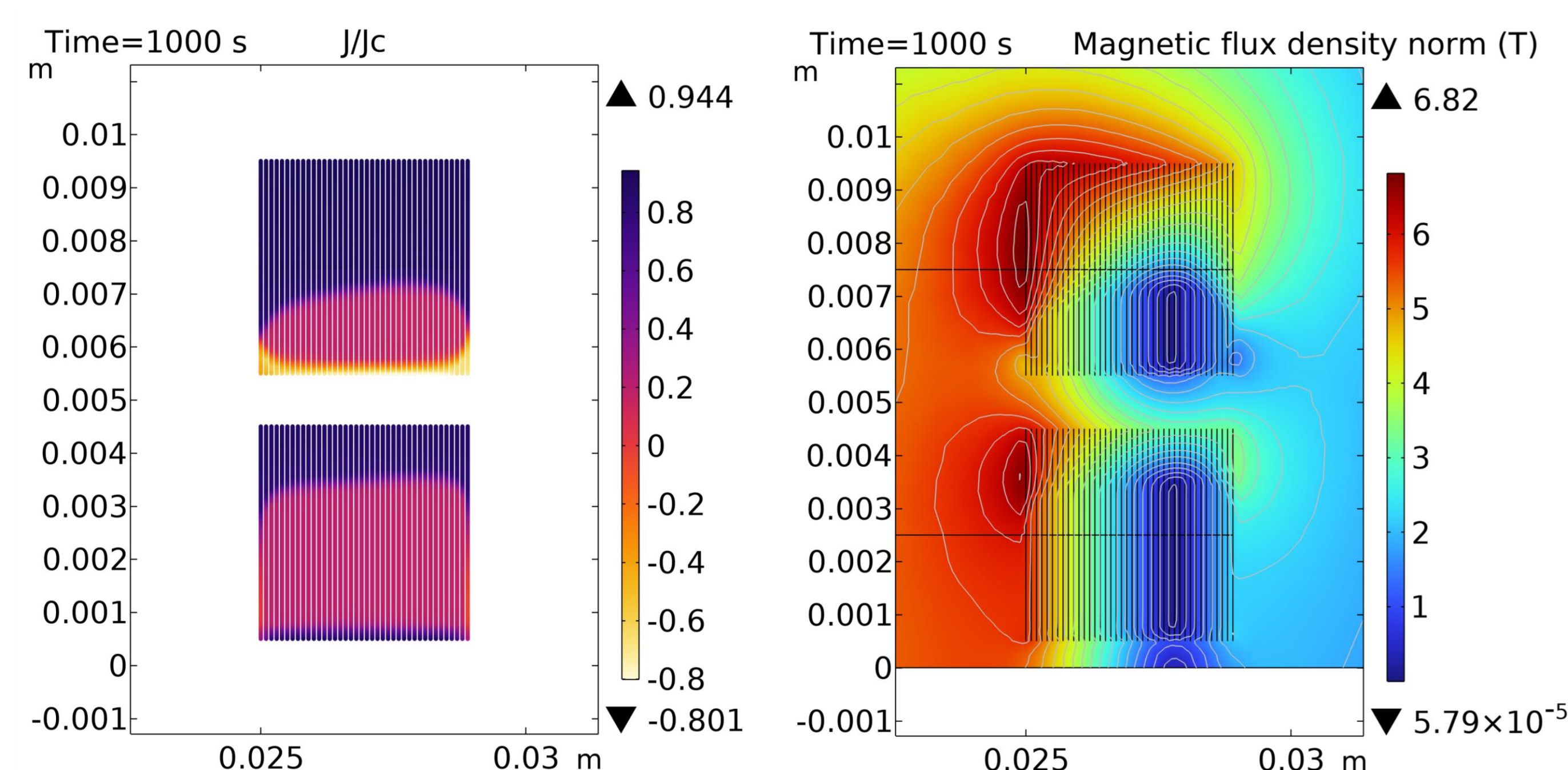
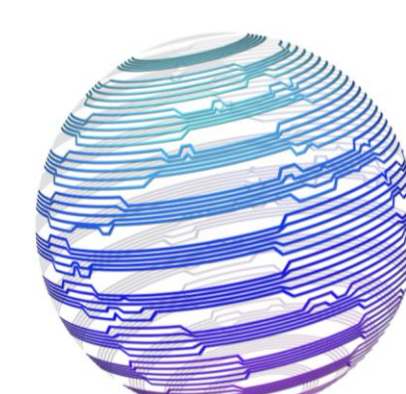


FIGURE 2. Left: ratio of current density to critical current density on the cross-section of the REBCO tapes, at $t = 1000\text{s}$. Right: magnetic flux density norm (T) on the 2D view, at $t = 1000\text{s}$.

REFERENCES

[1] - B. de S. Alves, A. Arsenault and F. Sirois, "2-D Thin-Shell Model Based on the H- ϕ Formulation for Modeling HTS Tapes in COMSOL Multiphysics," in IEEE Transactions on Applied Superconductivity, vol. 34, no. 9, pp. 1-10, Dec. 2024, Art no. 7500910, doi: 10.1109/TASC.2024.3473850



ATLED
ENGINEERING



contact@atledengineering.com
www.atledengineering.com
+44 7 93 39 24 764