Modelling Interactions Between HTS Tapes and Permanent Magnets

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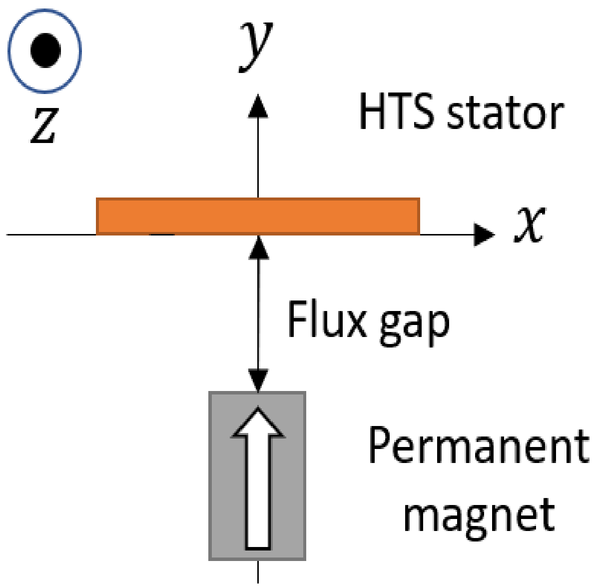
Context

- Permanent magnets (PMs) create highly inhomogeneous magnetic fields and are present in devices such as the high-temperature superconducting (HTS) dynamo.
- Widely available HTS coated-conductor tapes exhibit typical n-values of 20 - 60 and an angular magnetic field dependence on the critical current, $I_c(B, \theta)$.
- The Brandt analytical model poorly describes such devices, assuming a homogeneous magnetic field, operation within the Bean limit (n $\rightarrow \infty$) and a constant critical current.

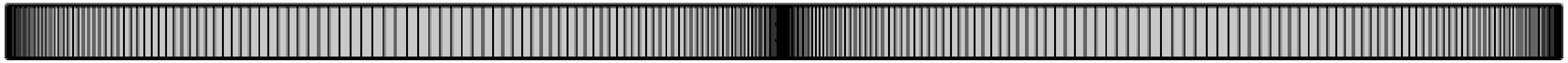
In this work, a finite-element model is constructed to describe the interaction between a coated-conductor HTS tape and a permanent magnet, which is the basis of an HTS dynamo, using COMSOL Multiphysics and measured current data from commercial tapes.

The Model

Problem Geometry



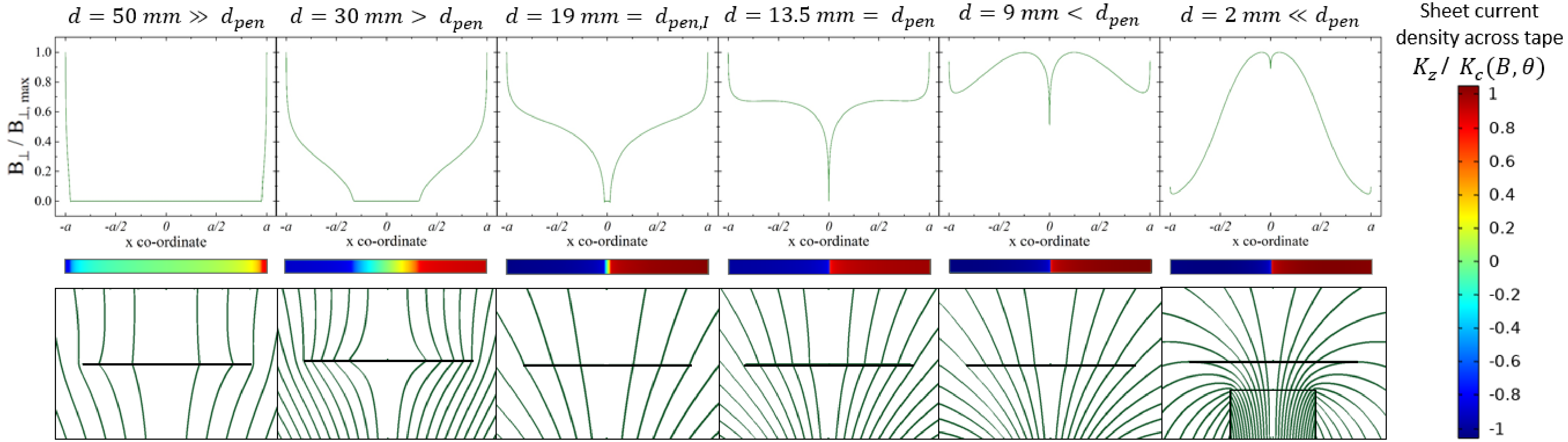
- 2D segregated **H**-formulation model in x-y plane as in [1, 2].
- PM movement, to vary the flux gap, is mimicked via a translation operator and models are coupled with appropriate boundary conditions.
- The HTS tape sub-domain uses two logarithmic meshes for greater clarity at the tape centre and edges:



1) L. Quéval *et al.*, "Superconducting magnetic bearings simulation using an *H*-formulation finite element model" *Superconductor Science and Technology*, vol. 31, no. 8, p. 084001 2018
2) M. Ainslie *et al.*, "A new benchmark problem for electromagnetic modelling of superconductors: the high-T_c superconducting dynamo" *Superconductor Science and Technology*, vol. 33, no. 10, p. 105009 2020

Key Result – 'Gull wing' field profile

A 'gull wing' shape is present in the perpendicular field profile across the HTS tape at flux gaps, d, below a threshold value, d_{pen}, at which the flux fully penetrates the tape. This isn't present when assuming a homogeneous field and forms due to the inhomogeneity of the magnetic field from the PM across the tape width.

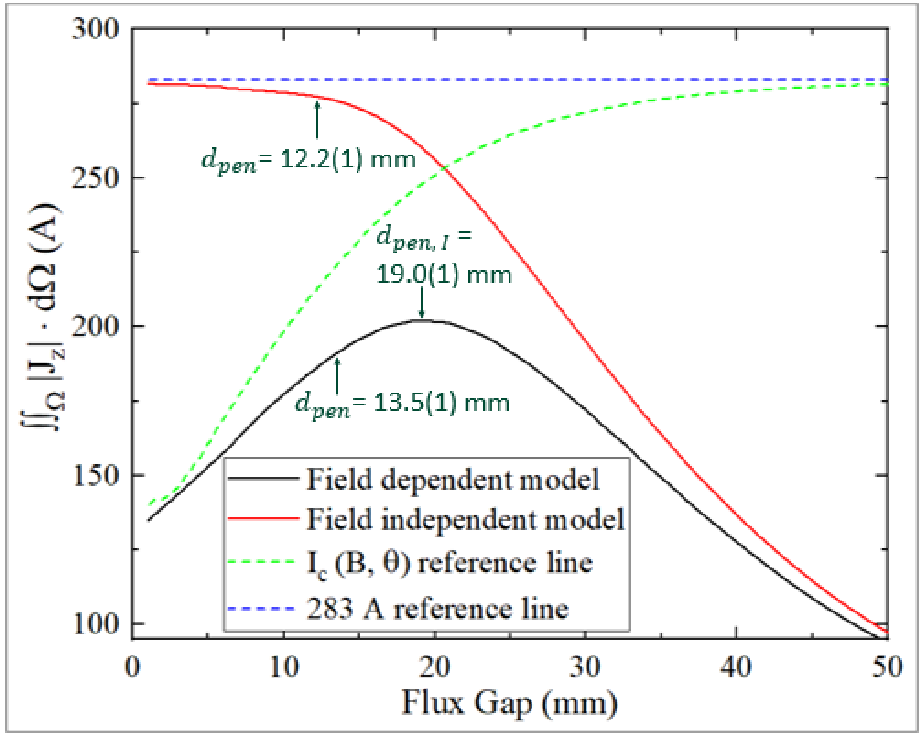


Key Results – Figures of Merit and $I_c(B,\theta)$ vs. Constant I_c

Full flux penetration of the HTS tape occurs at larger flux gaps when modelling using $I_c(B,\theta)$ data for the tape instead of a constant I_c, because the applied field suppresses the critical current.

Let $I_z' = \iint_\Omega |J_z| \cdot d\Omega$, where Ω is the tape sub-domain. In a model with a constant I_c, the current reversal zone becomes narrower as the magnet approaches the tape, and I_z' is asymptotic to I_c. When considering $I_c(B,\theta)$, there is a maximum due to field suppression of the critical current, and to calculate the flux gap of the maximum shielding current we can define

$$d_{pen,I} = argmax_d \iint_\Omega |J_z| \cdot d\Omega$$



Surface integrals of absolute current across the HTS tape as a function of flux gap using a 12 mm x 10 µm HTS stator and a 6 mm x 12 mm N52 grade PM, with the flux gap reduced from 50 mm to 0.5 mm at a rate of 0.5 mm/s. The model was run using field dependent $I_c(B,\theta)$ data with n = 20, as well as using a constant I_c of 283 A with n = 150.