Magnetic levitation between HTS tape coils and permanent magnets for rotary bearing applications

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1. Introduction – stacks of tape as composite bulks

2. HTS pancake coils and slabs samples

Two sample geometries were created, pancake coils acting as bulk cylinders for cylindrical bearings and a stack of tapes in the form of a slab for planar bearings. The pancake coils were wound by ASCG using uninsulated SuperOx tape (12 mm wide, 65 µm thick, Jc ≈ 430 A/cm2) having only silver stabilization. The slab was created with silver plated copper stabilized tape by SuperOx, compressing the tape layers ‘face to back’ with 735 N at 110°C. Cylindrical HTS PMs were used for both field cooling of the coils and slabs.

Cylindrical geometry (coils)

The graphs on the right show the hysteresis force curves obtained for the PM pair inside the 3 coils. The PMs were moved from their field cooled position at 1 mm/s, stopping every 0.2 mm for force measurement. Hysteresis is large at 77.4 K but mostly disappears at lower temperatures due to increased Jc. Over 300 N of force can be generated at 20 K which is close to the theoretical maximum predicted for a uniform bulk cylinder with infinite Jc, of the same dimensions as the coils. The theoretical curve comes from the Perfectly Trapped Flux (PTF) model which effectively ‘freezes’ the flux inside the superconducting domain at field cooling. A summary of the force curves is shown below along with a comparison to critical state (CS) modelling which accounts for real induced currents as elaborated in Section 4. There is reasonably good agreement in terms of force magnitude although the peak in force occurs at a larger displacement than predicted.

20K experiment, 45K CS model, 3 coils
45K experiment, 45K CS model, 3 coils
20K experiment, 77.4K CS model, 3 coils

3. Levitation force measurements between PMs and slabs

Cylindrical geometry (slab)

The graphs on the right show the hysteresis force curves obtained for the 25mm PM and the slab when field cooling at a 1.5 mm gap. The smaller forces are expected due to the lower field produced by the single PM, and significantly lower field gradients. The PM-superconducting active area is also 4 times smaller than for the cylindrical case. As for the coils, the hysteresis is reduced and force magnitude increased when lowering temperature. There exists a larger difference between the PTF model for an ideal superconducting and the 20 K force curve representing further optimisation of the slab for this levitation geometry.

4. Critical state modelling

A critical state model was developed in Comsol Multiphysics 5.1 using an E-J power law and the H-formulation to simulate induced currents dependent on both temperature and field [5]. Readily available data for SuperOx tape was used to create an effective engineering current density for the coils with a Kim field law dependence and temperature dependent, lift factor fitted to data. A temperature and field dependent α value was also used for reliable creep force simulation.

\[ I_c = J_c B + J_v \]  \quad (\alpha T, \alpha B) \]

5. Conclusions

- Stable axial magnetic levitation has been proven for HTS tape coils and slabs acting as composite superconducting bulks with cylindrically symmetric field sources. This is despite the samples having < 2% (REBCO) by volume.
- Forces over 300 N were measured which, for the lower temperatures, is close to that expected for an ideal bulk with infinite Jc.
- The pancake coils were potential to be used as passive components in cylindrical type bearings and the slabs in planar type bearings for applications such as flywheel energy storage
- The main practical advantages of stacks of tape such as the coils and slab tested are: consistent superconducting properties, dynamic stiffness, high thermal stability and mechanical strength giving them potential for engineering applications.

FUTURE WORK
- Future tests include using wider tape for coils and slabs and also using 40 mm tape annulus which allow netting current circulating through them.
- A variety of stacking arrangements for slabs can be evaluated and experiments scaled to test larger slab sizes.
- Dynamic stiffness tests will be performed for amplitudes < 1 mm and frequencies > 10 Hz which is relevant for applications.