A Miniature Linear Actuator

based on a layer-wound *Re*BCO solenoid

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EUCAS2023 Bologna, Italy 3rd-7th September

Abstract

We describe the design and first winding tests of a cm-sized superconducting voice-coil actuator based on an insulated *Re*BCO solenoid in combination with a pseudo-Halbach permanent magnet array. High-tech cryogenic precision equipment can benefit from superconducting coils due to their high current density, while at the same time decreasing heat in-leak and ohmic dissipation.

Project introduction

Maximise force per volume/weight, "mug"-sized

Minimise (internal) heat dissipation

Application range:

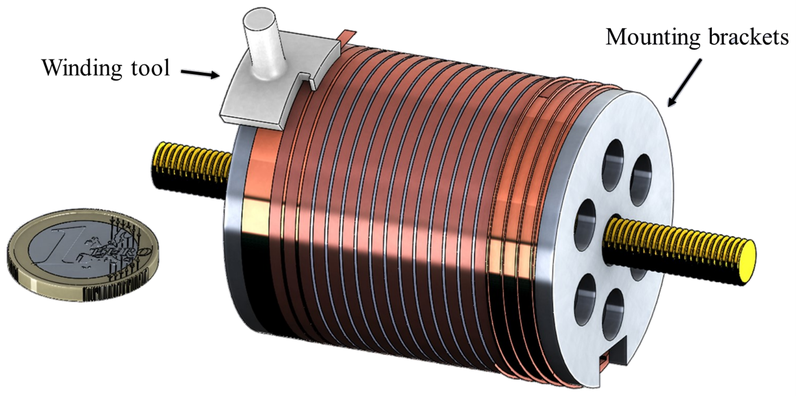
"...in-between piezo-drives (µm-to-mm) and large-scale electromechanical actuators (cm-to-m)."

- Parallel research line at University of Twente:
  - Grow coil structure directly on a former

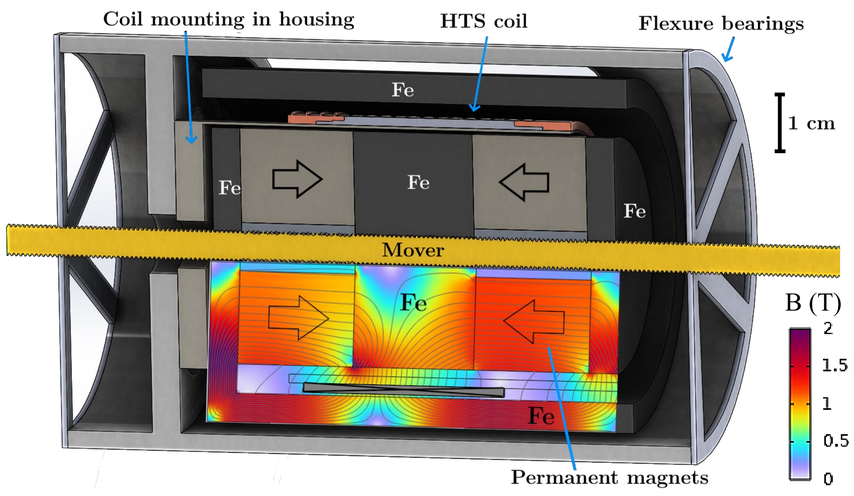
Preliminary actuator design

- Ease of manufacturing: layer-wound solenoid rather than pancake stack
- Less common but successfully demonstrated [1]
- Narrow (2 mm) tape
  - Easier "hard-way" bending
  - Lower heat load through current leads

Ti tubular former, Cu terminals (Ø 45 mm)



- Pre-design and sensitivity analysis on electromagnetics:
  - Concentric moving magnet design
  - Pseudo-Halbach *Re*-based permanent magnets
- Up to 15 turns per layer and up to 25 layers
- Designed for 300 N axial actuation force based on 20 layers operating at 77 K

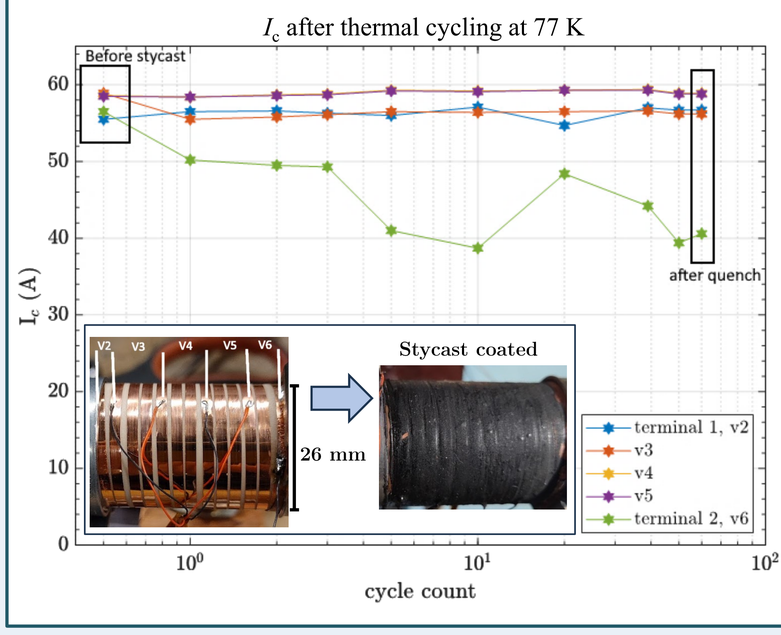


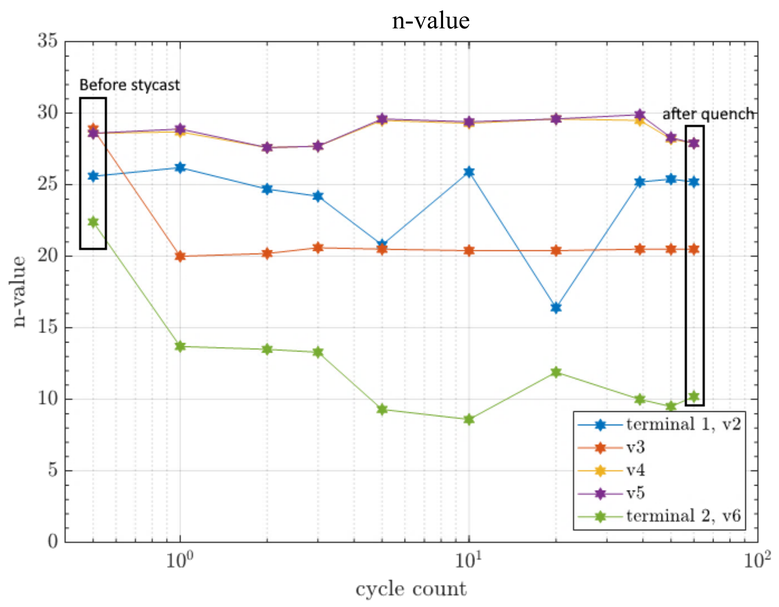
Thermal cycling of an epoxy coated single-layer winding

- Preliminary winding and insulation tests (single layer)
- Small radius winding (Ø 26 mm) on Al_2O_3 tubular former
- Coated with Stycast 2850FT:
  - Thermal cycling: no degradation
- Current contacts not sufficient, new terminal design required

SuperOx tape specification

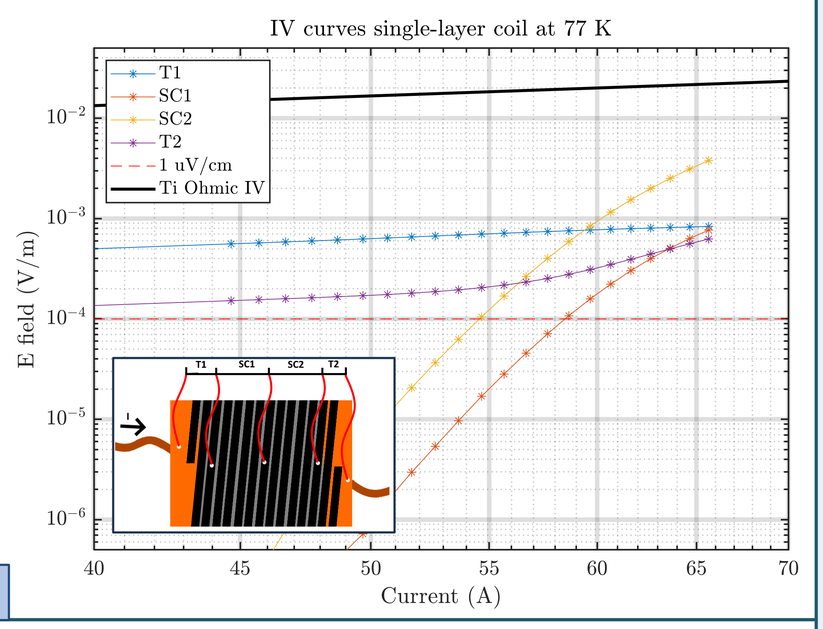
Parameter	Value
Width	2 mm
Substrate	30 µm
Stabiliser	5 µm Cu
I_c	60 A





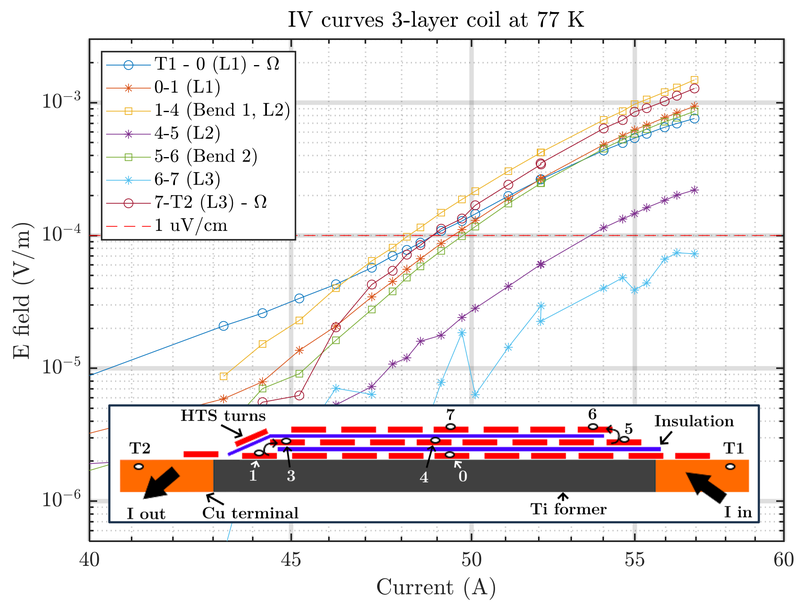
Former design validation

- Single-layer winding of 14 turns with a tension of 4 N (~65 MPa)
- Terminals work as intended; no alarming resistance or degradation
- Insulation/thermal design needs attention:
  - Epoxy coating insulates
  - Modelling temperature increase [2]



Multi-layer winding

- Tape geometry: layer transition introduces in-plane bending
  - In practice: tape buckles slightly to minimise bending energy [3]
- Same size coil with 3 layers of 8 turns each
  - Wet-wound using Stycast 2850FT
  - Layers insulated with glass fibre
- Lower I_c due to coil self-field
- Layer transition minimal effect



Conclusions

- The main design choices have been made and a design for a demonstrator actuator is in progress.
- First experience with winding techniques using 2 mm wide SuperOx *Re*BCO tape has been gathered. A small 3-layer coil was successfully made.
- The small coils do not experience significant degradation after 50 thermal cycles.

Acknowledgements

This work is funded by VDL Enabling Technologies Group BV and the Dutch government. The *Re*BCO tape was kindly supplied by SuperOx.

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[1]: C. Barth et al. (2016), IEEE TAS 26(4), 1-9

[2]: A-H. Bergen (2020), [PhD thesis, University of Twente]

[3]: T. H. Nes et al. (2022), Supercond. Sci. Technol. 35 105011