Screen-Current-Induced Nonuniform Strain on REBCO Conductor: An Experimental and Analytical Study with Small Coils Wound with Monofilament and Striated Multifilament REBCO Tape

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OUTLINE

- Introduction: Mechanism of The Screening-Current-Induced Nonuniform Strain along Tape width
- Small-Coil Experiment to Observe and Measure the nonuniform Strain: with Small Coil Wound of Monofilament and Striated Multifilament REBCO Tape
- Numerical Method to Simulate Screening-Current-Induced Nonuniform Strain
- Proposal: Reduction of The Strain Difference by Using Striated Multifilament REBCO Conductor

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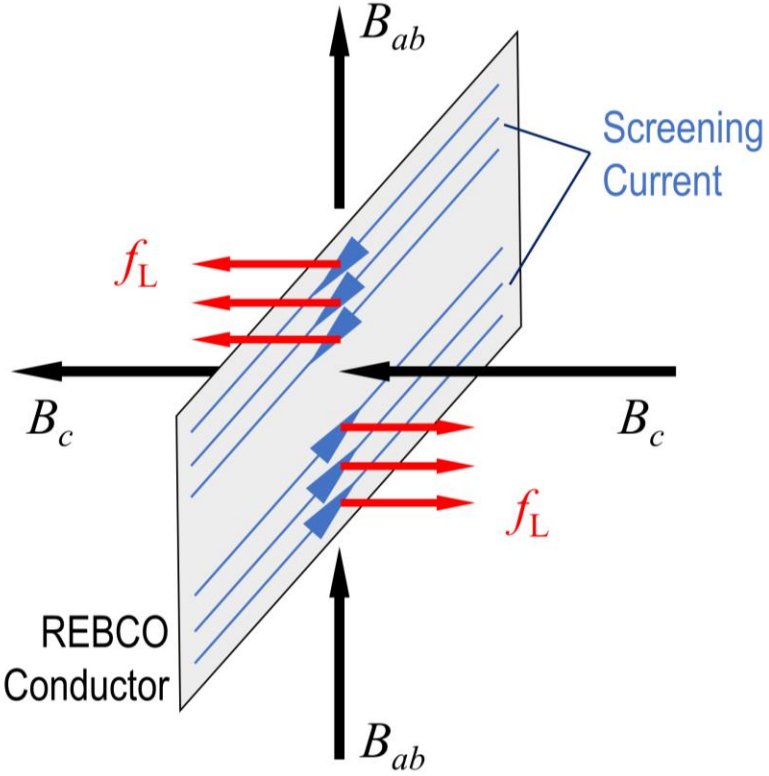
INTRDUCTION

Mechanism of the Screening-Current-Induced Nonuniform Strain

When A REBCO Superconductor Is Exposed to the Magnet Field …

- The REBCO conductor is *MAGNETIZED* with a close-loop *SCREENING CURRENT* induced to screen the perpendicular component B_c of the field;
- The nonuniform current distribution leads to a nonuniform Lorentz force f_L, resulting in a magnetic *TORQUE* on the conductor;
- In a REBCO *MAGNET*, nonuniform Lorentz force means a *NONUNIFORM HOOP STRAIN* on the conductor.



Proposal: *Striated Multifilament* REBCO Tape To Reduce Strain Nonuniformity

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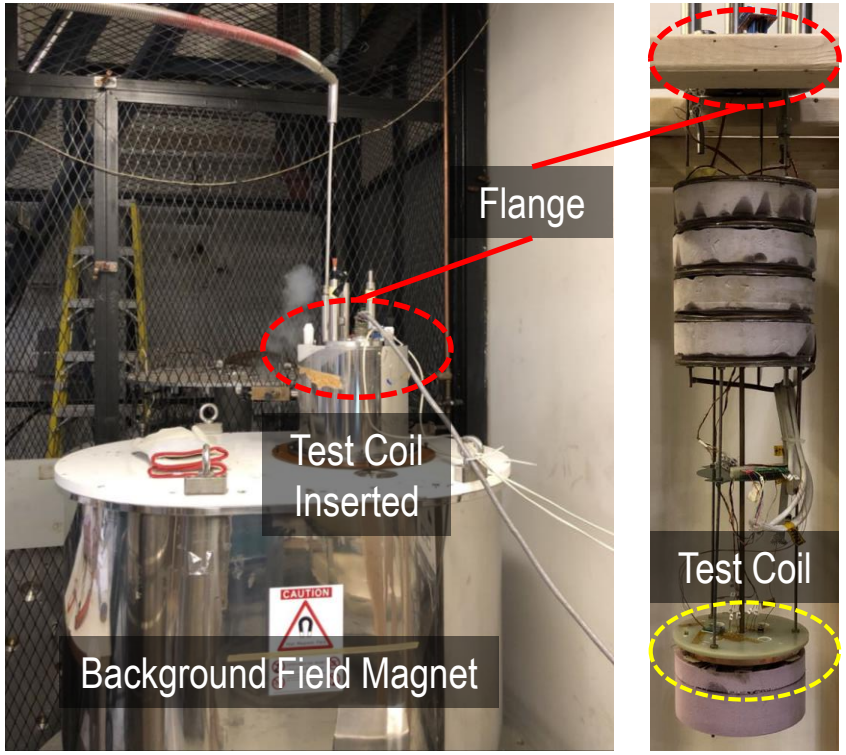
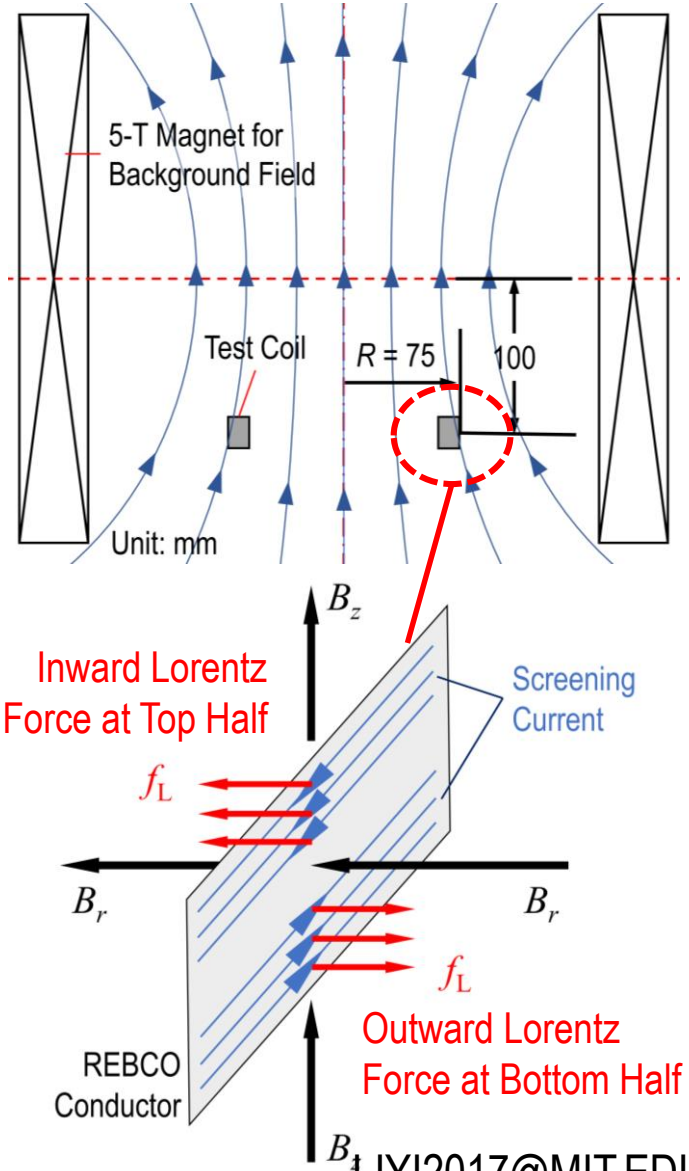
EXPERIMENTAL APPROACH

Excitation of Screening Current with A Background Field

- A small REBCO coil is prepared and inserted into a 5-T background magnet, 100 mm off the center plane.
- A screening current, *i.e.* nonuniform strain, is induced on the REBCO conductor when the background field is applied.





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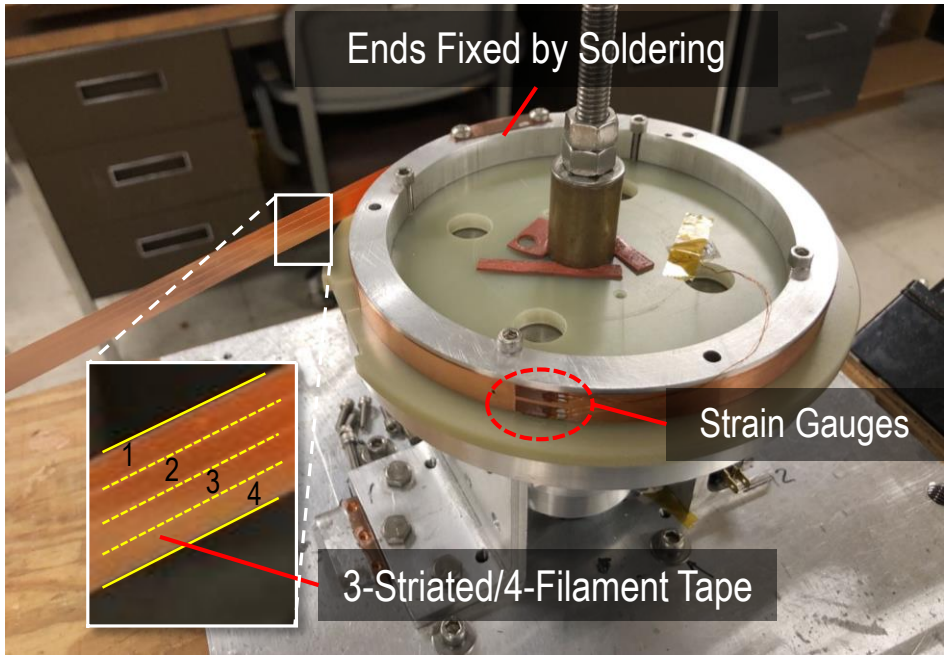
EXPERIMENTAL APPROACH

Small REBCO Test Coils

Designed For Detection

- Small turn number (3) to deepen field penetration
- 150-mm large diameter to increase hoop stress
- 10-mm wide conductor for stronger magnetic torque



REBCO Test Coil

Turn Number	3 turn with REBCO facing inward
Dimension	150-mm Inner Diameter
Insulation	2.5-mil Kapton Co-Wound
Structure	Aluminum Bobbin and G10 Plate
Excitation	Open Circuit without Input Current

REBCO Conductor

Manufacturer	Shanghai Superconductor
Dimension	10-mm Width; 63-μm Thickness
Substrate	50-μm Thick Hastelloy
Stabilizer	2 Layer of 4-μm Thick Copper Plating
Critical Current	370 A @ 77 K, Self-Field
Filament	Monofilament and 3-Striate/4-Filament

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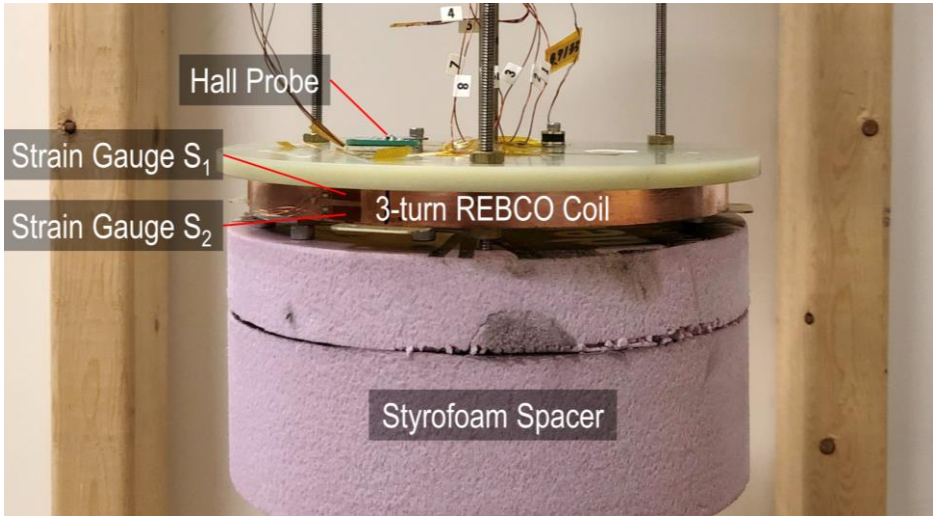
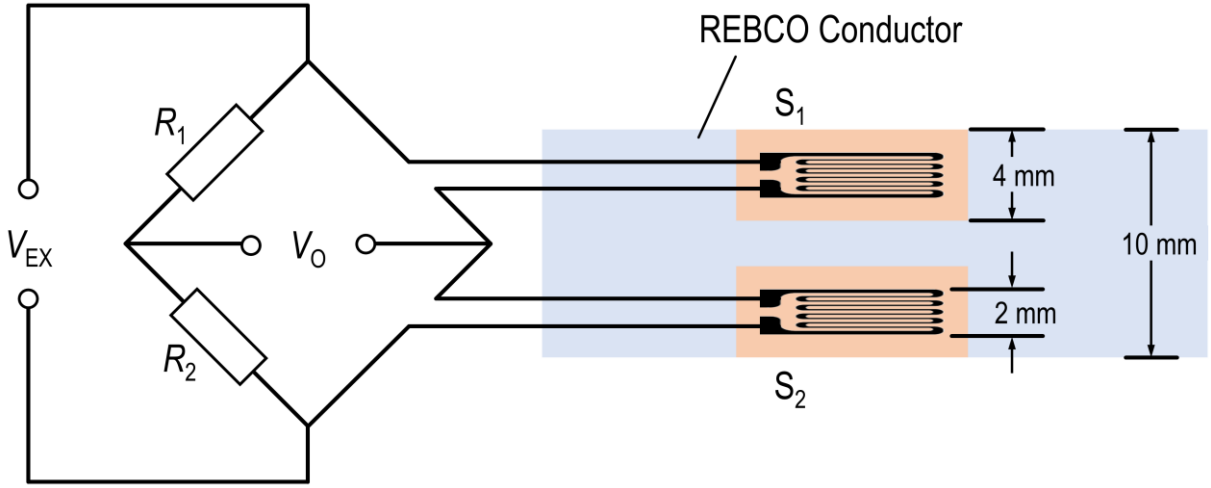
EXPERIMENTAL APPROACH

Detection of Nonuniform Hoop Strain

Strain Gauges

- Attached on the substrate side of the outmost turn
- 4-mm total width with 2-mm wide effective area
- Half-bridge circuit to detect the nonuniform strain
- Monitored with Micro-Measurement System 8000





Estimated Strain Difference

Using "Half-Bridge" Circuit

$$\Delta\varepsilon_2 - \Delta\varepsilon_1 \sim \frac{4}{GF} \cdot \frac{V_O}{V_{EX}}$$

GF: Gauge Factor

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NUMERICAL METHOD

Screening Current Analysis with *T-A* Formulation

Strategy of Numerical Simulation

1. Screening Current with T-A Formulation (Time Dependent)

⇩

2. Lorentz Force according to the Screening Current

⇩

3. Stress and Strain Analysis (Stationary)

T-A Method for 2D-film Conductor

E*-*J Relationship $$E_\phi(J_\phi) = E_0 \left|\frac{J_\phi}{J_c}\right|^n \cdot \frac{J_\phi}{|J_\phi|}$$

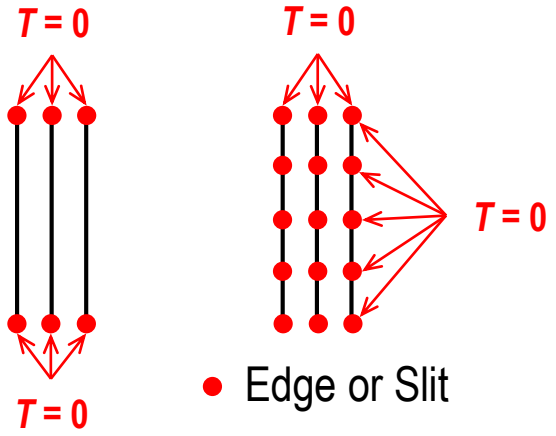
T-Formulation $$J_\phi = \mathrm{d}T/\mathrm{d}z$$

Faraday's Law $$\frac{\mathrm{d}}{\mathrm{d}z}E_\phi(J_\phi) = -\frac{\partial B_r}{\partial t}$$

The field $\boldsymbol{B}$ is solved with vector potential $\boldsymbol{A}$ using FEM

Boundary Condition $T = 0$ (Constant)

Cross Section of REBCO Conductor



● Edge or Slit

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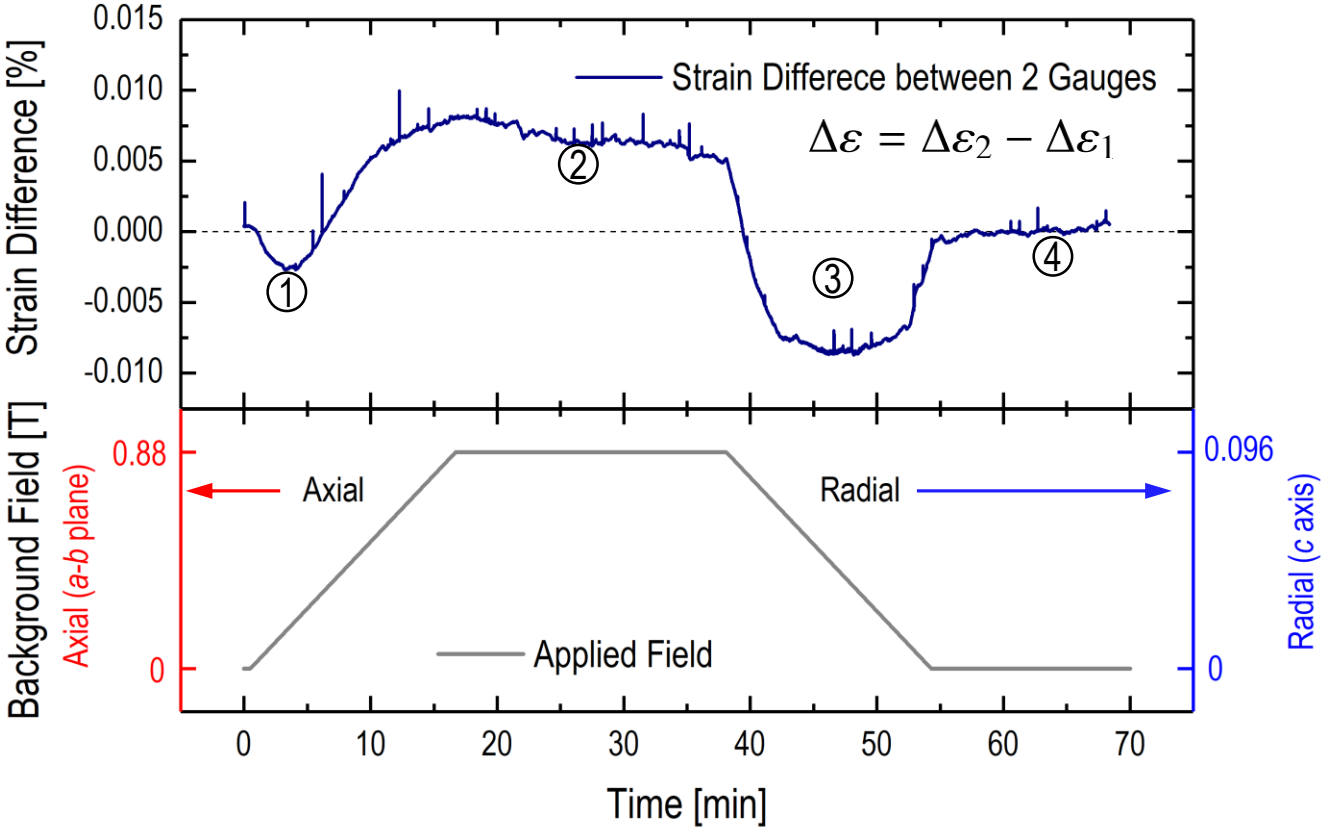
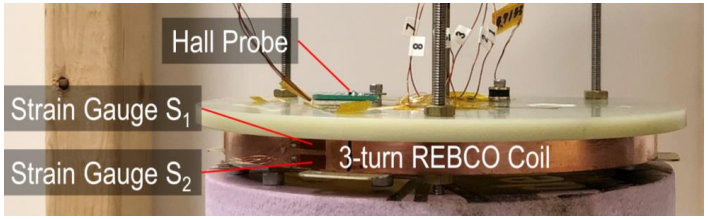
PRILIMENARY TEST

Screening Current Effect Confirmed in Liquid Nitrogen Test

We observed and *CONFIRMED* the screening-current-induced nonuniform strain in the LN_2 test with coil wound of 10-mm monofilament REBCO tape.





① Since this is not the first run, a negative signal is observed due to the dominance of a residual screening current induced in the last run.

② The strain difference reached a saturation because of the low J_c @ 77 K in the external field.

③ The new screen current induced during ramping down completely overwrote the original one.

④ The strain difference vanished with the background field withdrawn.

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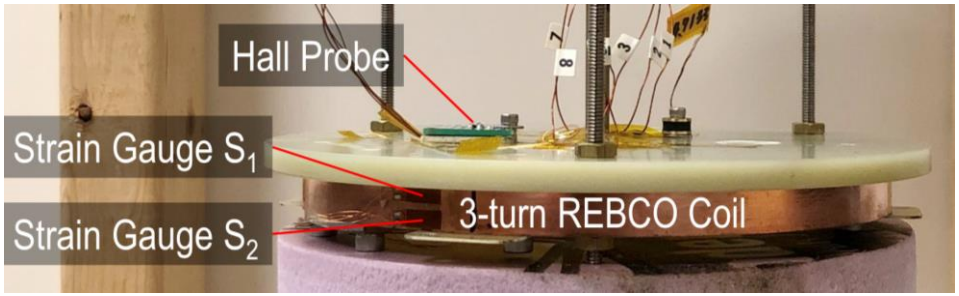
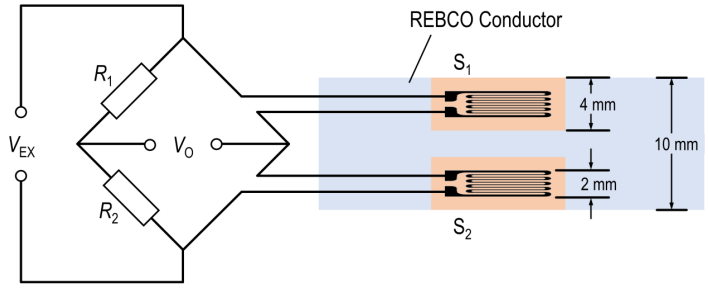
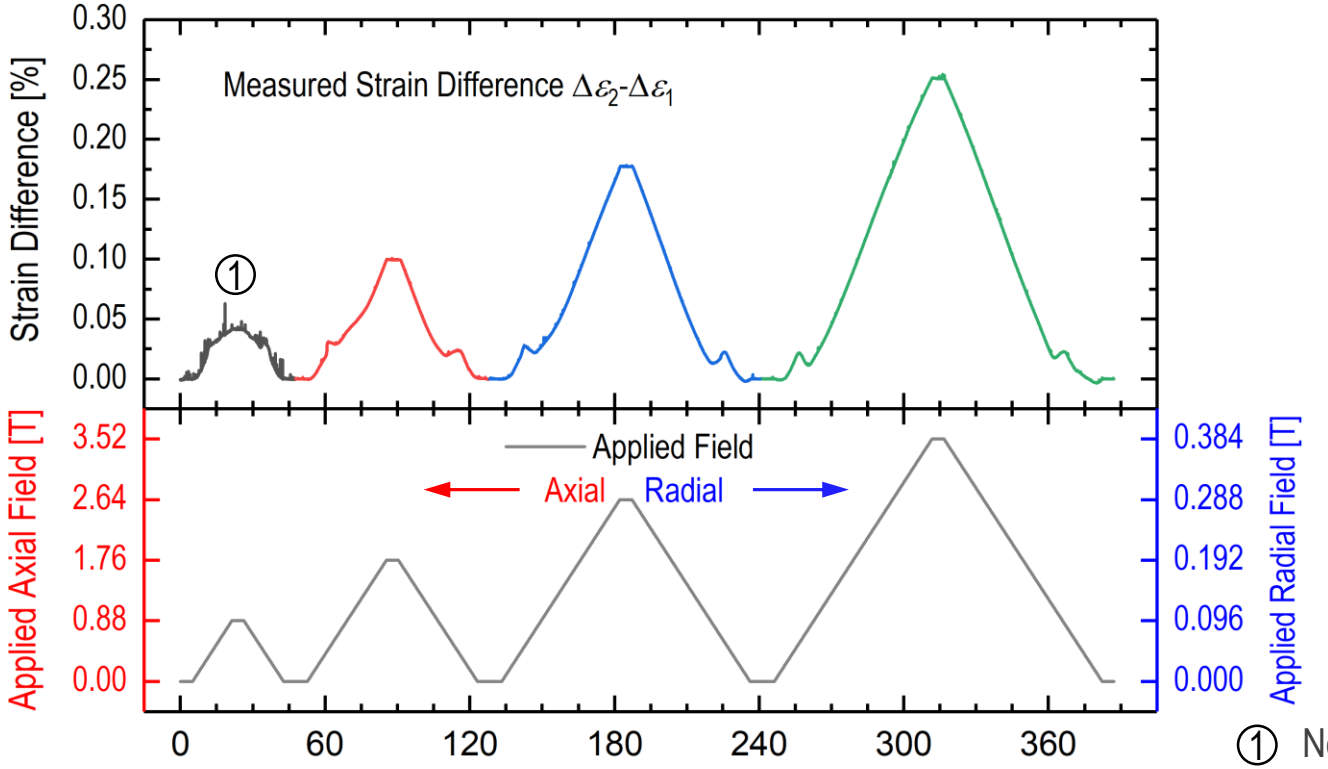
DETAILED EXPERIMENTAL RESULTS

Coil Wound of *Monofilament* Tape, Tested in Liquid Helium







Strain Difference

$$\Delta\varepsilon_2 - \Delta\varepsilon_1 \sim \frac{4}{GF} \cdot \frac{V_O}{V_{EX}}$$

GF: Gauge Factor

① Noisy signal due to low excitation voltage V_{EX}

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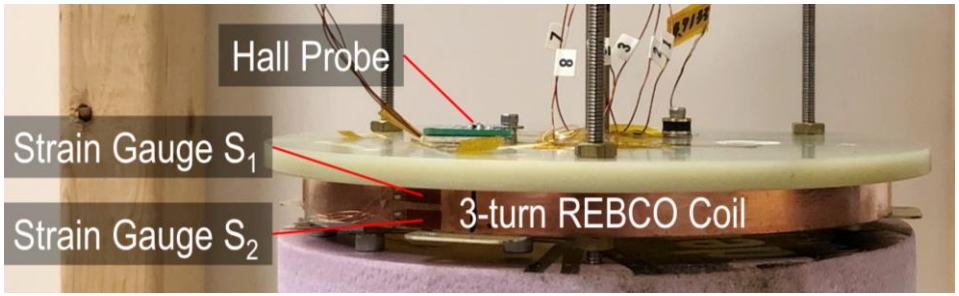
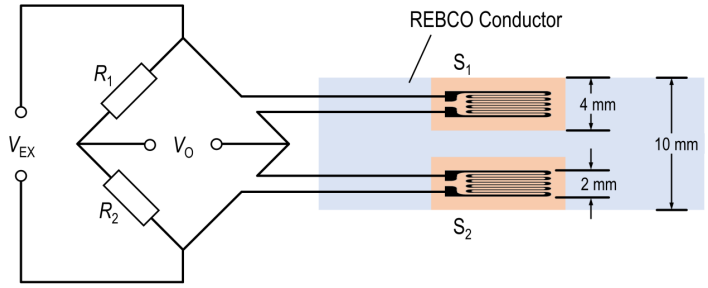
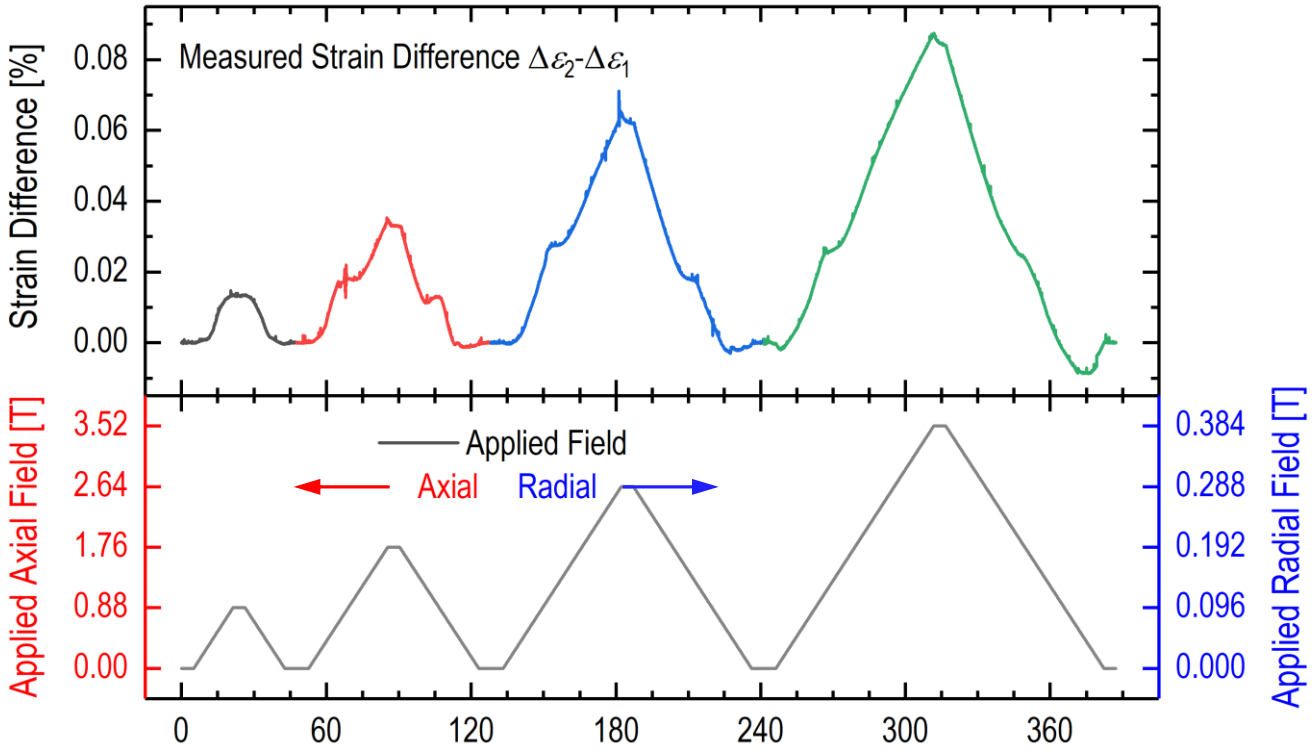
DETAILED EXPERIMENTAL RESULTS

Coil Wound of *3-Striate/4-Filament* Tape, Tested in Liquid Helium







Strain Difference

$$\Delta\varepsilon_2 - \Delta\varepsilon_1 \sim \frac{4}{GF} \cdot \frac{V_O}{V_{EX}}$$

GF: Gauge Factor

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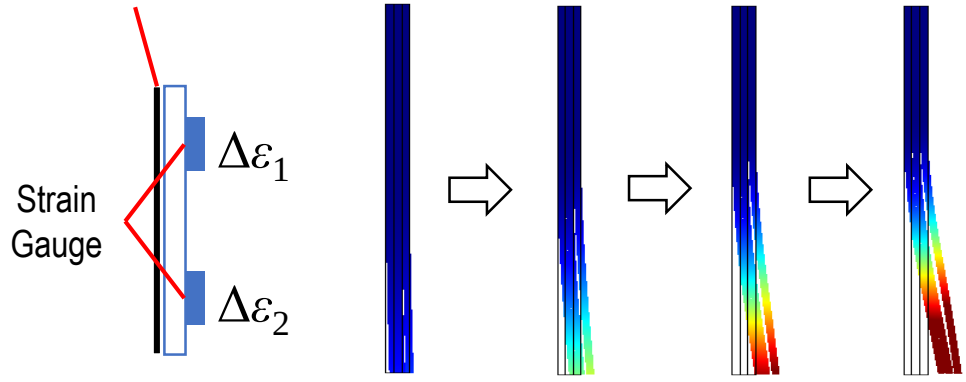
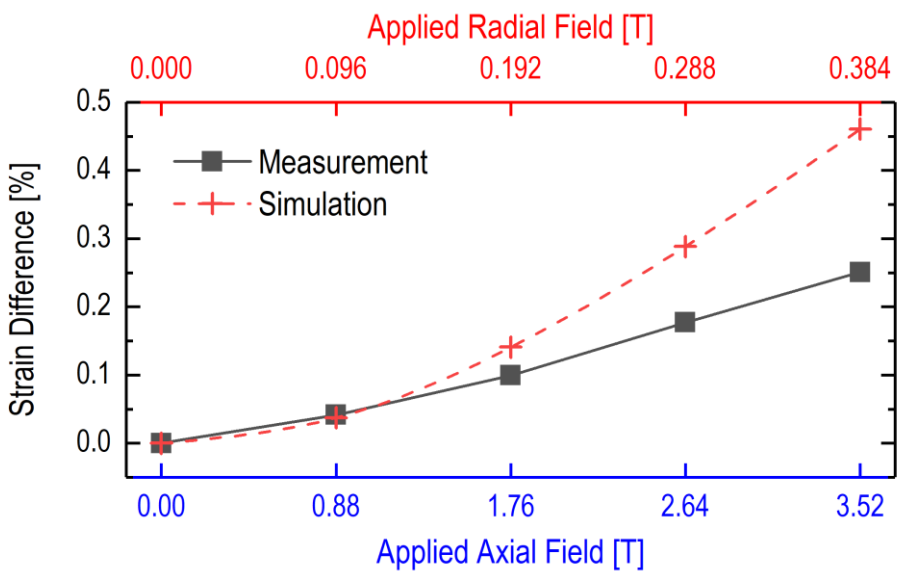
COMPARISON AND DISCUSSION

Mono-Filament vs *3-Striate/4-Filament*, Experiment *vs* Simulation

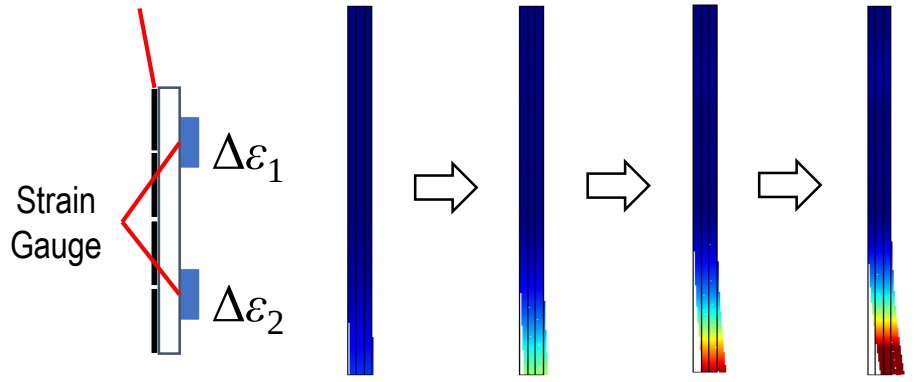
Monofilament

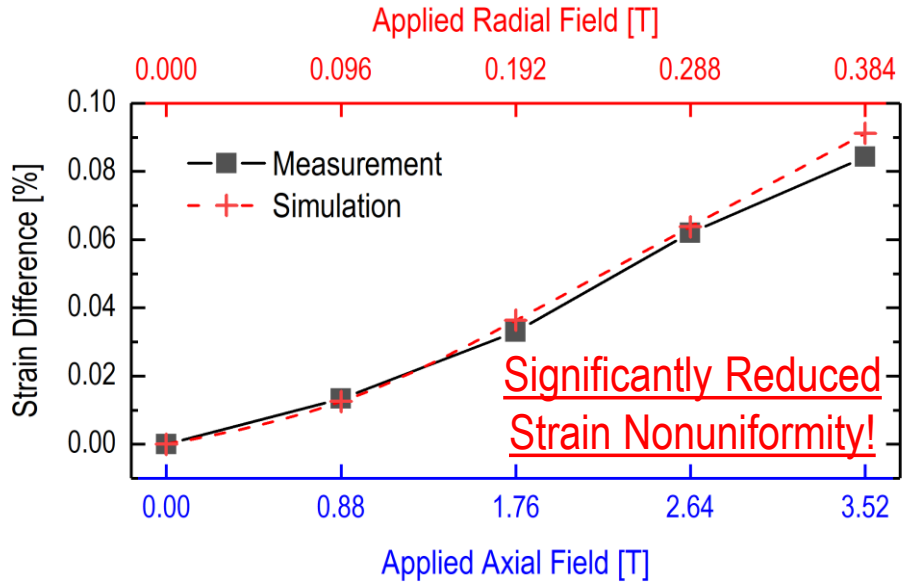




3-Striate/4-Filament

Sacrifice A Single Filament to Save the Whole!





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CONCLUSION

- Screening Current Not Only Cause Field Distortion, But Also Unexpected *Nonuniform Strain* along the width of REBCO Conductor;
- Screening Current Induced Nonuniform Strain Observed in Small Coil Test;
- Numerical Simulation of Screening Current Induced Nonuniform Strain Matched Experiment Well in When Deformation Is Small;
- *Striated Multifilament* REBCO Conductor to Effectively Reduce Strain Differences along Tape Width.

You may find more information from the listed presentation:

Thu-Af-Or23-01: Construction and Test Results of a Cryogen-Free 23.5-T REBCO Magnet Prototype towards a Tabletop 1-GHz Micro-coil NMR Magnet

THANK YOU FOR WATCHING!

Shall you have any comments or questions, please do not hesitate to contact me!

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