Development of quench tolerant epoxy impregnated ReBCO coils for an HTS MRI magnet

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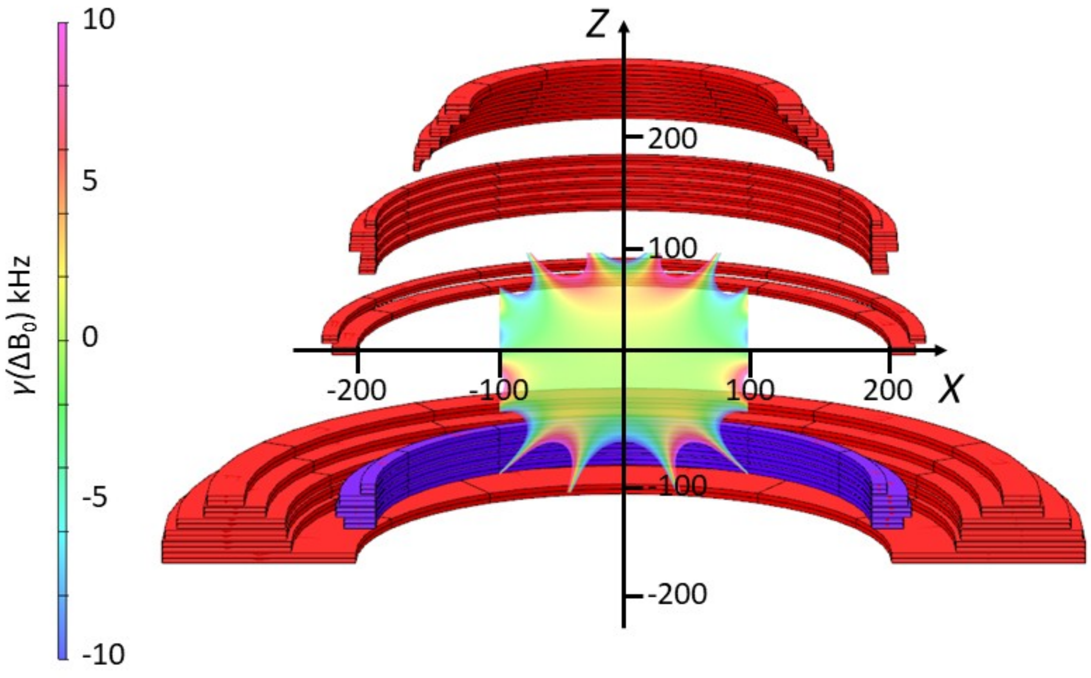
Motivation: 1.5 T REBCO brain imaging magnet

- Brain imaging magnet for use with poor field uniformity pulse sequences
- 15 km REBCO conductor
- 5.1 T peak field for 1.5 T centre field
- Inductance ~25 H
- 23 coils



- Coils with negative (inwards) hoop stress
- Quench tolerance desired
- Reasonable ramping times
- Uniform turn density in the coils

Existing winding techniques

Option 1:

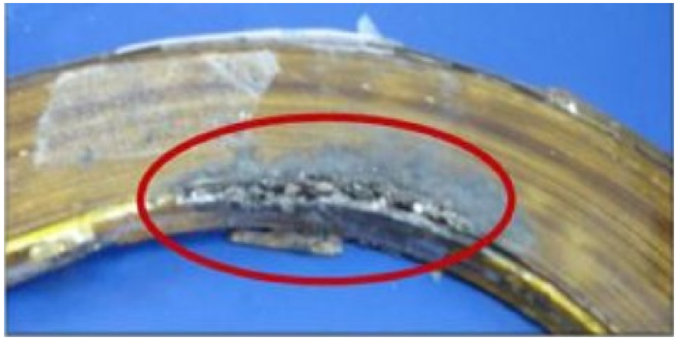
No-insulation coils and variants

✓ Good quench behaviour
x Long ramping times
x **Mechanically unstable coils**

Option 2:

Epoxy impregnation

✓ Coil becomes a composite block - good mechanical stability
x Delamination problem due to shrinkage mismatch
x Quench vulnerability



Can we put the two options together?

Hybrid approach: Epoxy impregnated coils to give finite resistance between turns

Epoxy Resin

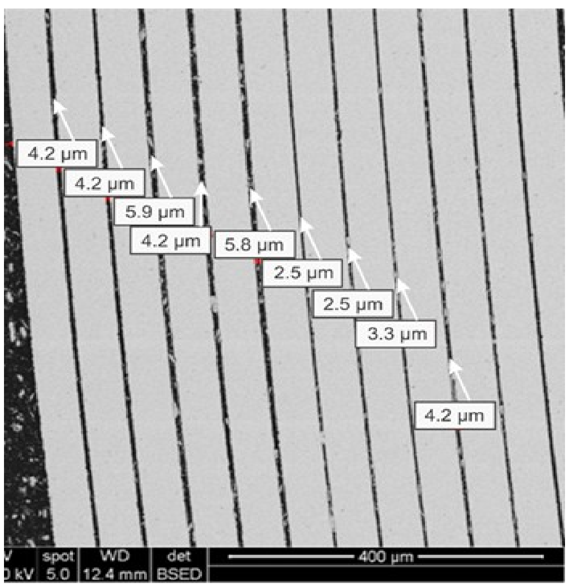
+

Conductive powder to achieve conductivity between turns

+

Shrinkage inhibitor to match expansion coefficient

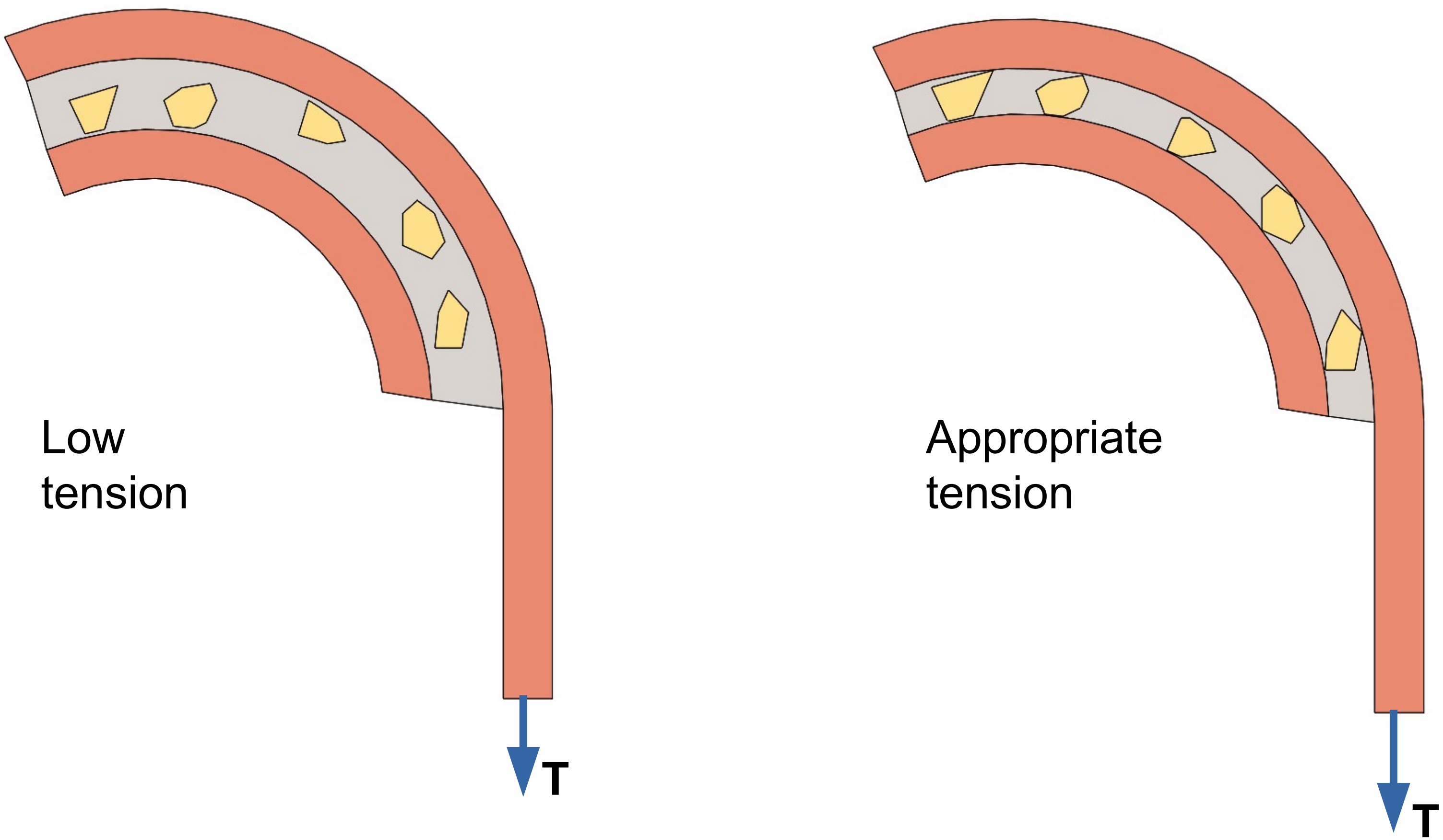
=



- Relatively thick resin blend
- Wet winding is required
- **No uniformity in turn spacing**

Uniform turn spacing

Addition of a third or a dual purpose filler with a narrow size distibution used as a gauging material



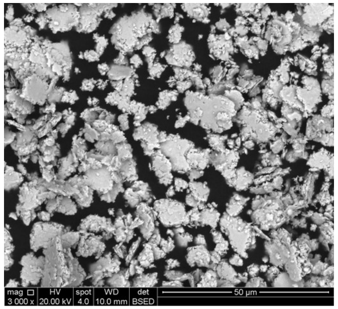
Final blend formulation

Epoxy resin filled with:

- Copper as conductive material
- Monocrystalline synthetic diamonds used as shrinkage inhibitors and gauging particles

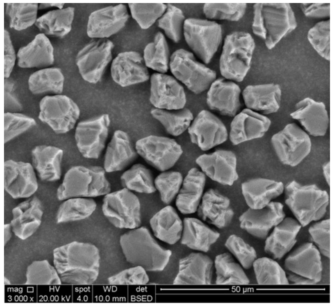
Resin

+



Copper

+



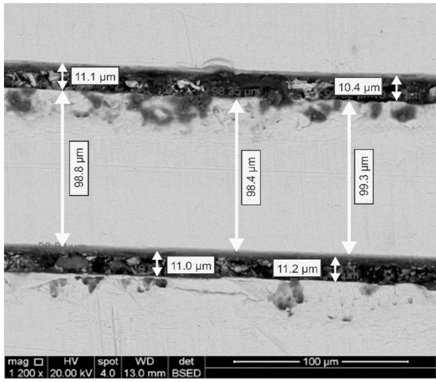
Diamonds

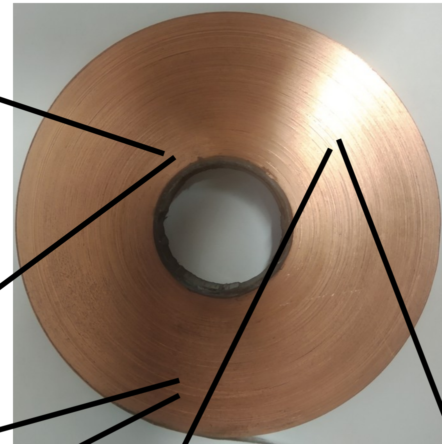
=

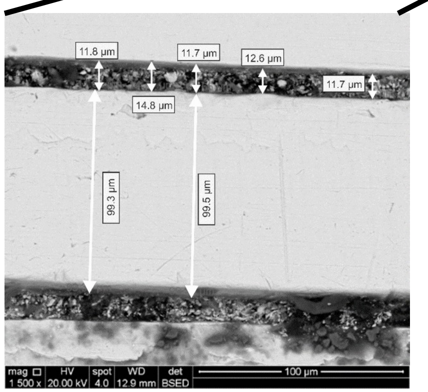
Verification of the winding technique

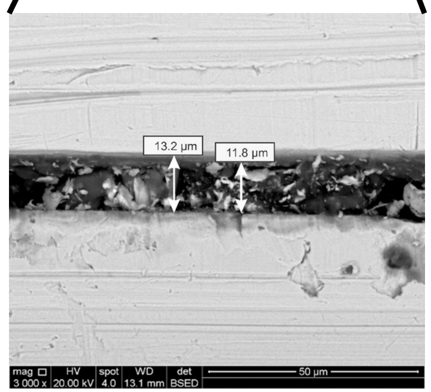
- Gauging
- No delamination
- Conductivity between turns
- Quench tolerance
- NMR field stability

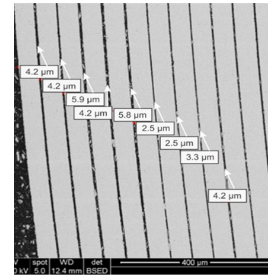
Gauging verification

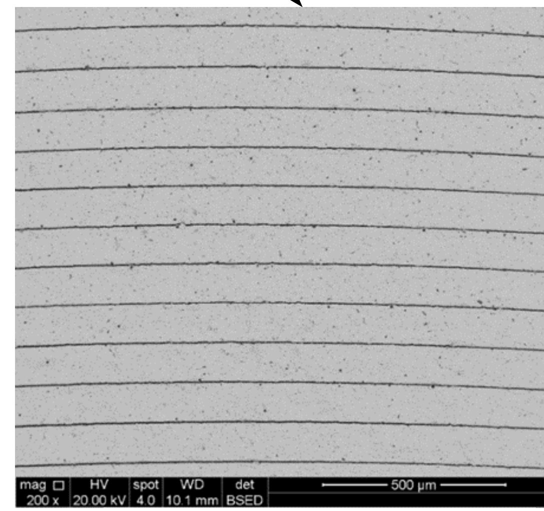








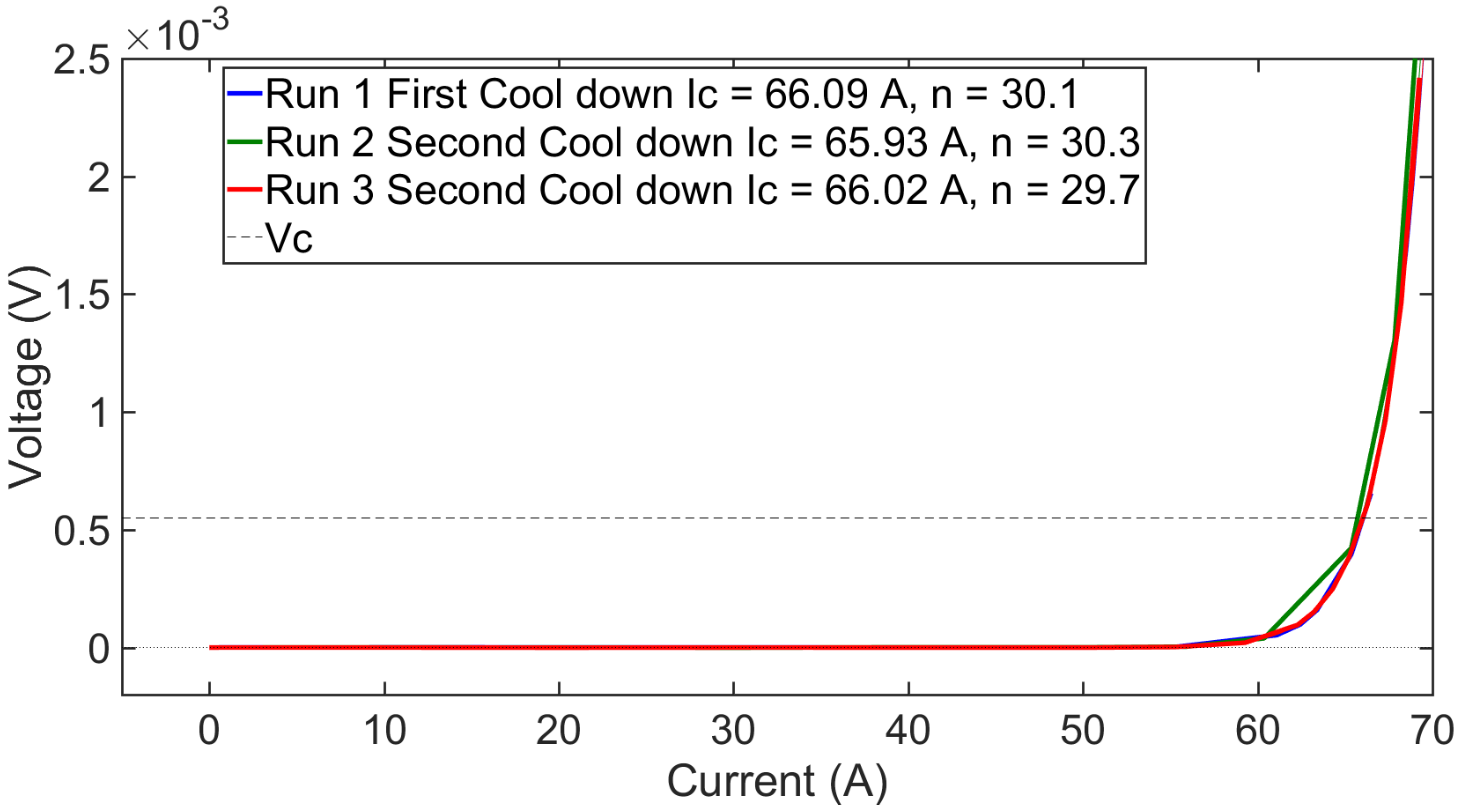




Example Coil

ID [mm]	24.5
OD [mm]	71.7
Turns	200
Conductor Thickness [mm]	0.1
Resin thickness [µm]	11.8

Coil thermal cycling



- LN_2 @ 77K
- 1h cooling down
- 1h warming up

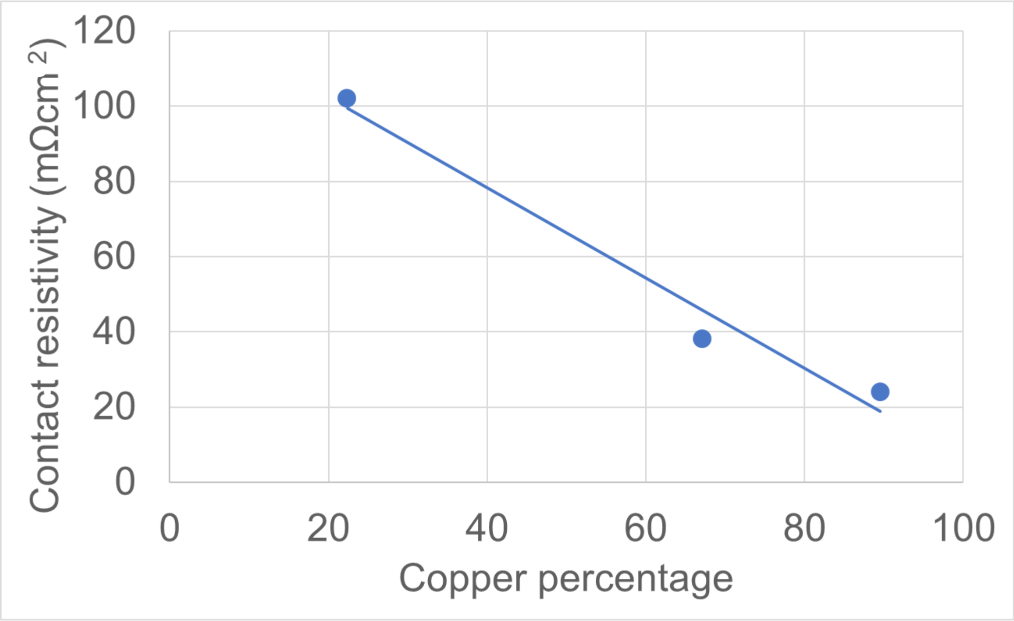
No significant degradation in I_c was observed hence, there is no delamination

Test Coil	ID [mm]	OD [mm]	Turns	Gauging [μm]	Diamonds % blend	Copper % blend
	24.9	45	50	13.05	45	45

Tuneable electrical conductivity

	Coi1	Coil2	Coil3
ID [mm]	24.9	24.9	24.9
OD [mm]	44.8	44.8	44.8
Turns	50	50	50
Copper % in blend by weight	**22**	**67**	**90**
Contact resistivity [mΩcm²]	**102**	**38**	**24**
Gauging [µm]	12.7	12.7	12.7
Inductance [µH]	100	100	100

Test on three SC coils

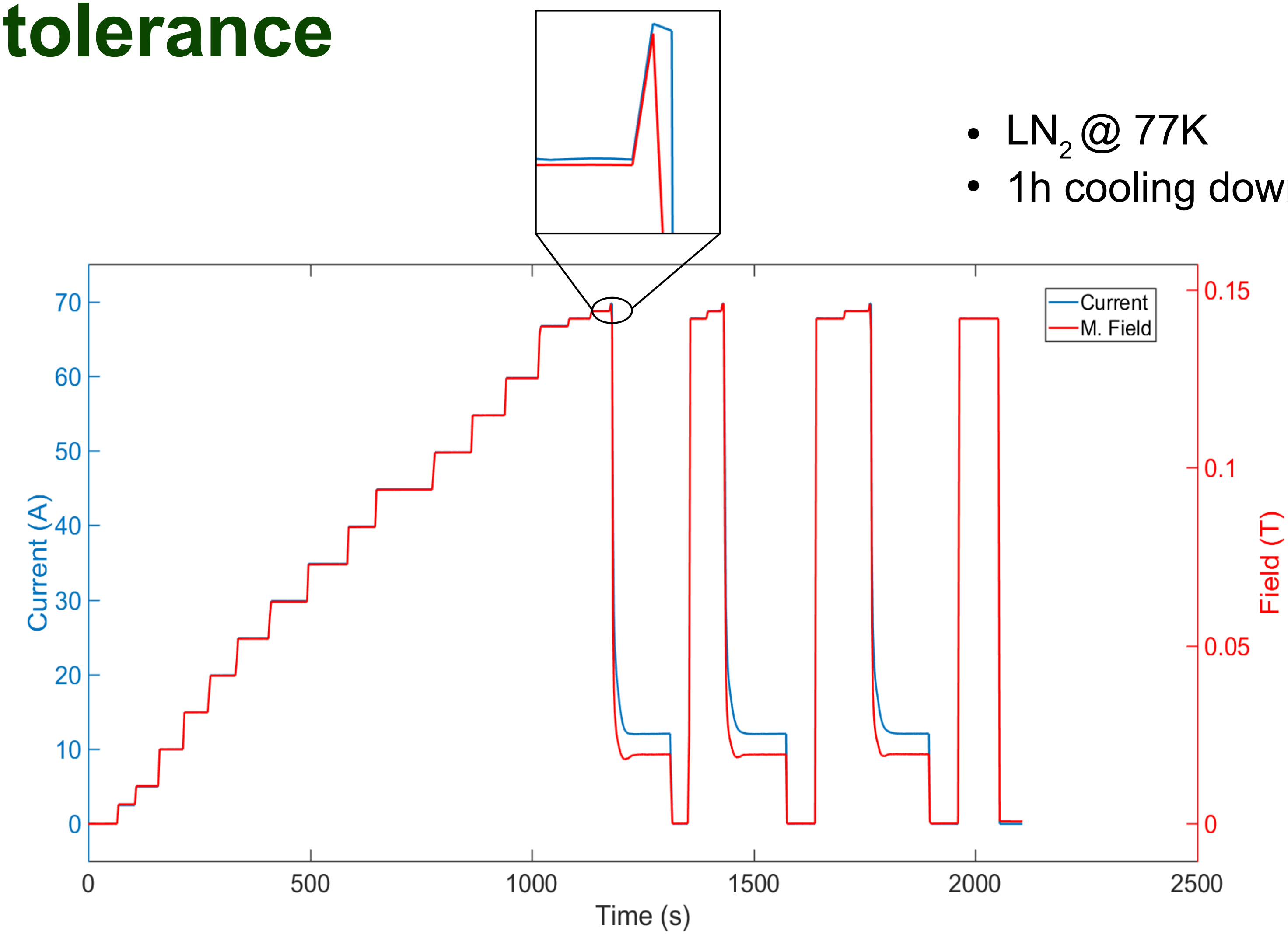


Quench tolerance

- LN_2 @ 77K
- 1h cooling down

Test Coil

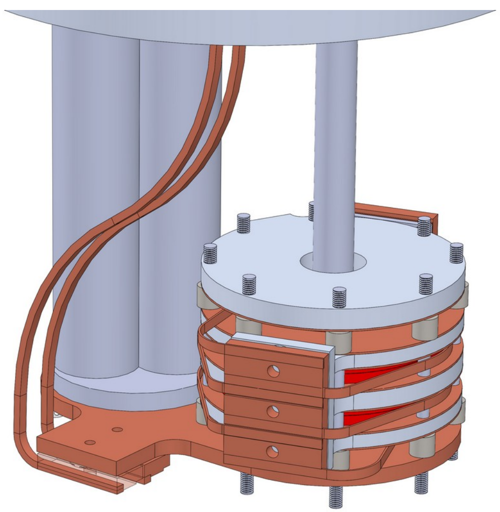
ID [mm]	24.9
OD [mm]	44.8
Turns	50
Gauging [μm]	12.7
Contact resistivity [mΩcm²]	**24**
Test temp [K]	77
Time const. [μs]	260

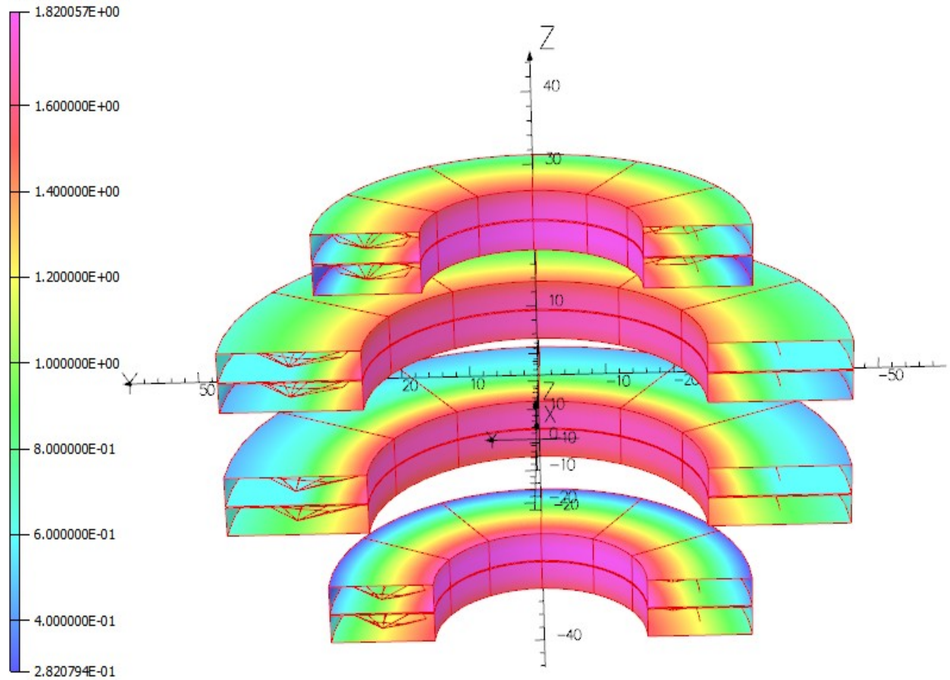


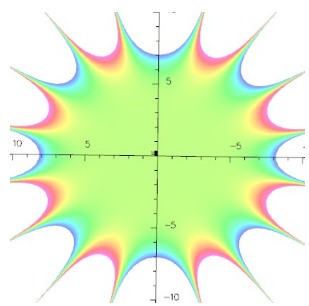
Coils can survive multiple quenches without degradation

Field stability: Test cryo-free NMR magnet

- 130 m of wire in 4 coils
- 65 mΩcm^2 contact resistivity
- 1.8 T peak field
- 1.5 T centre field
- 160 A
- Cryogen free
- Coil heaters are included
  to induce local quenches

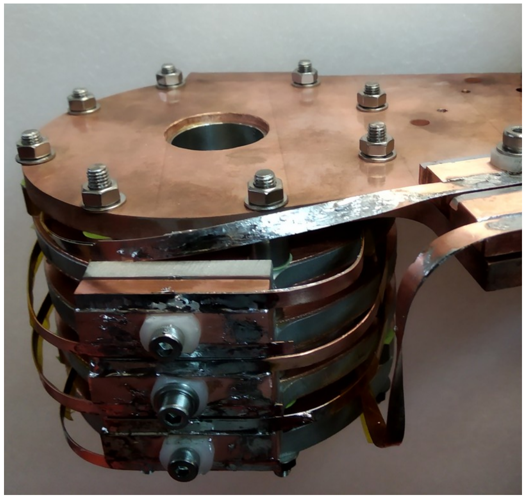


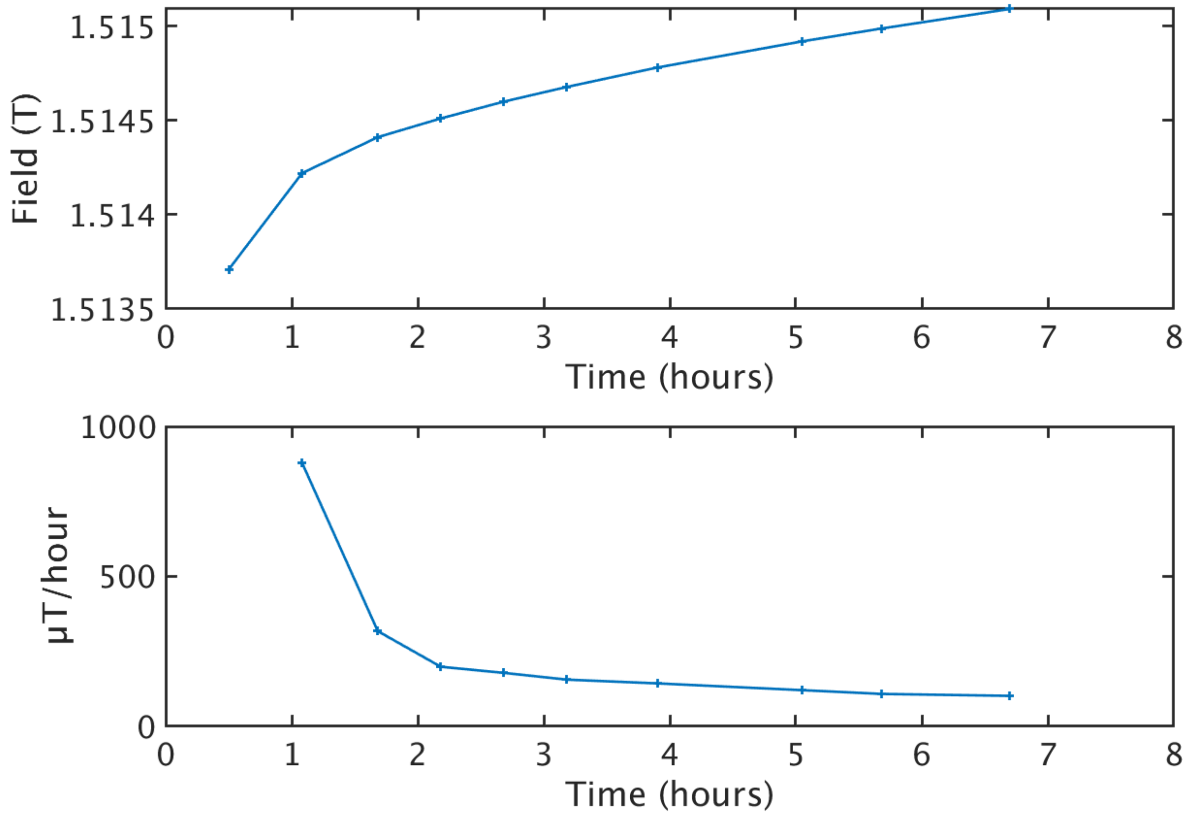




+/- 10ppm contours over 10mm x 10mm volume

NMR field stability





We believe drifting is due to screening currents as the magnet currently operates at ~50% of I_c

Conclusion

- Developed a winding technique using a conductive and low shrinkage epoxy.
- Demonstrated we can epoxy impregnate coils having:
  - Mechanical stability
  - Quench tolerance
  - Uniform turn spacing
  - Tuneable contact resistivity

Next steps

- Continue with quench and field stability tests on the NMR magnet.
- Apply and test the developed technique on larger diameter coils.
- Use the feature of tuneable contact resistivity to improve heat distribution during fast ramping and quench situations.

Acknowledgments

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