3D modelling of HTS Ring Magnet

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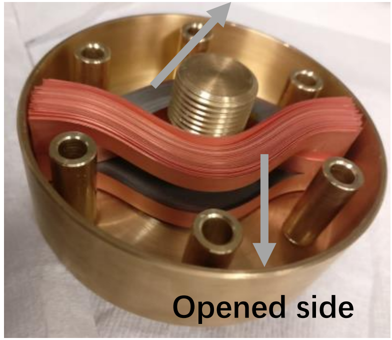
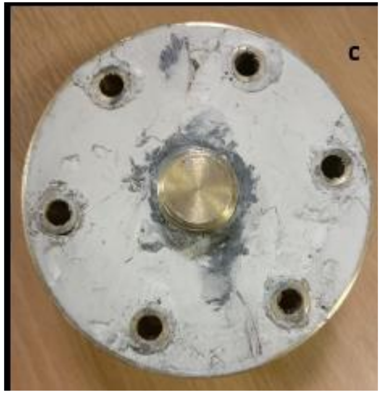
CONTENTS

1.1 Fabrication of ring magnets

Closed side





paraffin impregnation

Splitting HTS tapes

↓

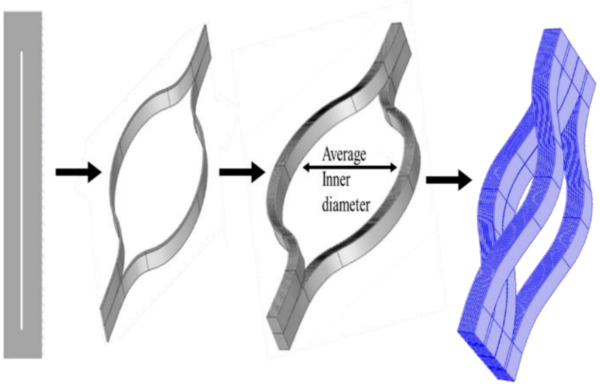
Create stacks

↓

Arranging stacks

↓

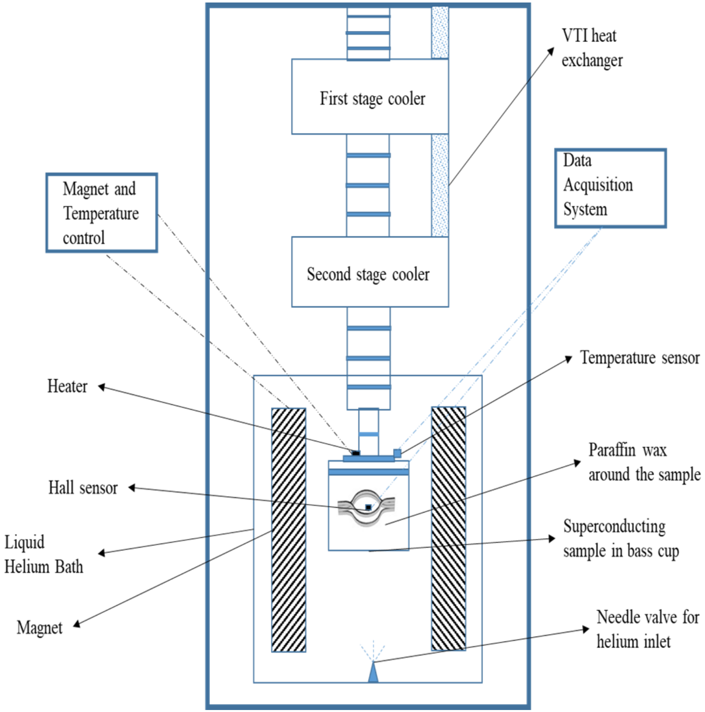
Encapsulation



Structure of the ring magnet

Sample parameters	Value
Inner magnet diameter	10 mm
Outer magnet diameter	90 mm
Ic of each tape	500 A
No. of rings	200
Tape supplier	Superpower

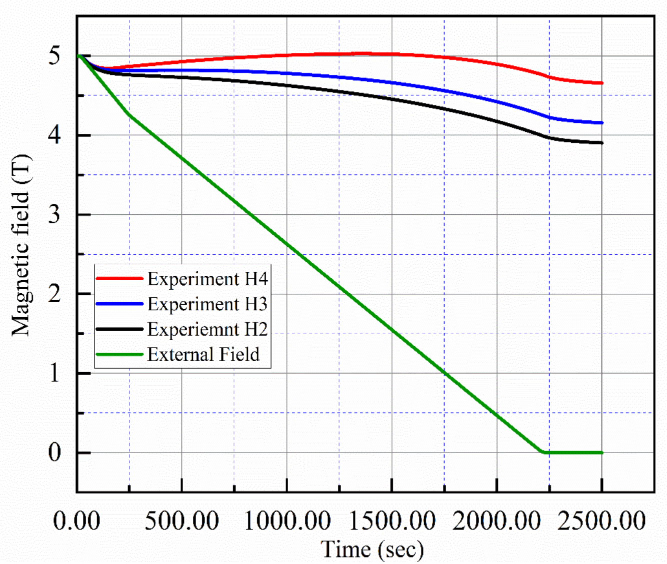
1.2 Magnetization



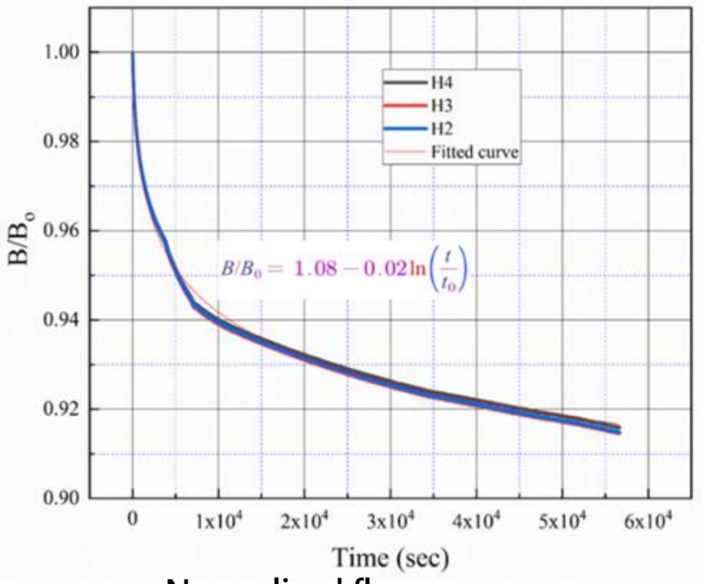
Experimental setup configuration at University of Cambridge. Bulk Superconductivity Group

System parameters	Value
Sample space	100 mm
Cooling medium	He
Temperature of sample	25 K
Hall sensor used	3
Applied field	5 T
Ramping rate	0.1 T/min

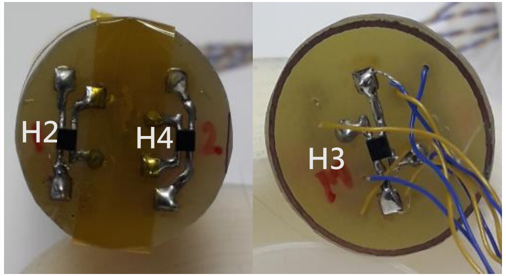
1.2 Field cooling results



FC Experiment



Normalised flux creep

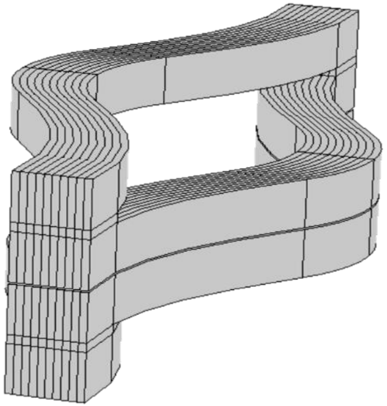


Hall sensor mounted on double sided PCB board.

- H2,H3,H4 represent the position of the Hall Sensors
- The maximum Trap field obtain in this experiment is 4.6 Tesla
- Reduction in trapped field during first two hours is 2.5% while overall reduction in 16.7 hours is 5.3%

2.1 3D homogenized stacks model

One single HTS domain with 10 HTS rings



3D COMSOL geometry of 2*100 HTS rings

Two assumptions were made in the homogenized model

- First, the thickness of the HTS layer has been artificially increased from 1 μm to 74 μm, which is the total thickness of the tape.
- Second, it is assumed that every 10 HTS rings has the same critical current penetration depth.

2.2 H-formulation

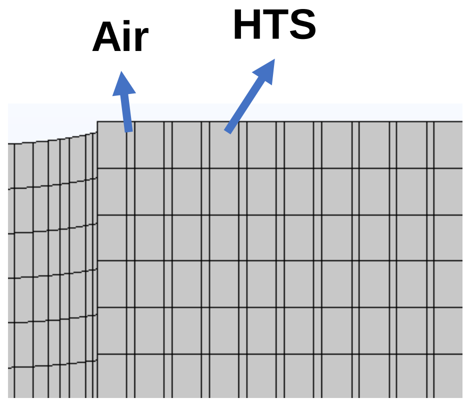
Governing equations

$$\mu_0 \mu_r \frac{\partial H}{\partial t} + \nabla \times (\rho \nabla \times H) = 0$$

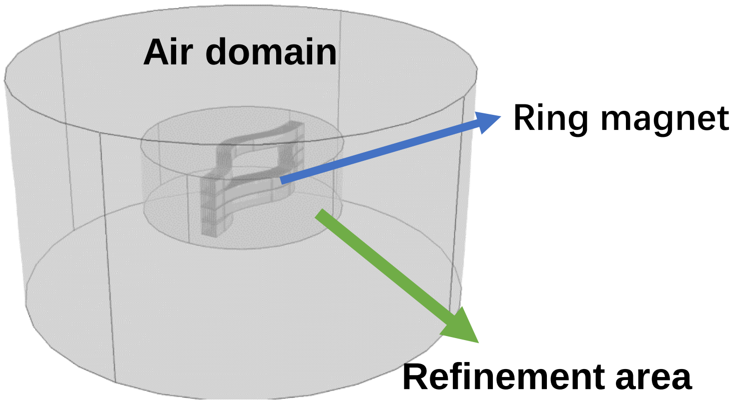
ρ Is governed by E-J power law

3D E-J power-law

$$\begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = E_0 \begin{bmatrix} \frac{J_x}{J_n}\left(\frac{J_n}{J_c}\right)^n \\ \frac{J_y}{J_n}\left(\frac{J_n}{J_c}\right)^n \\ \frac{J_z}{J_n}\left(\frac{J_n}{J_c}\right)^n \end{bmatrix}$$



Stacks of the ring magnet



2.3 Modelling results

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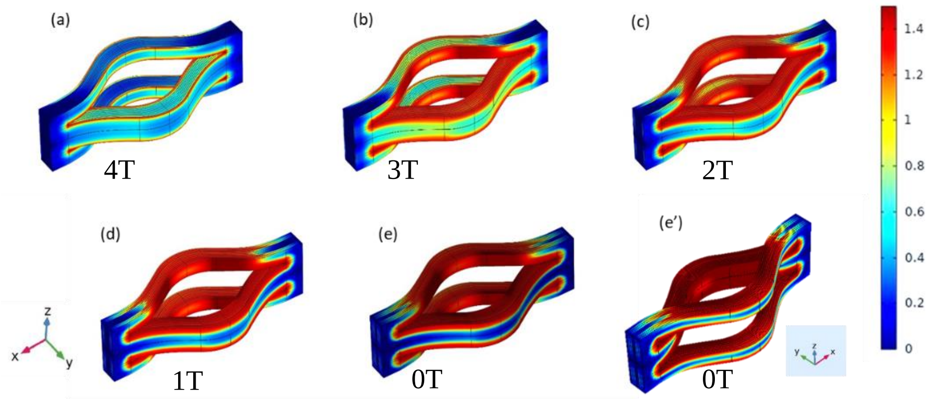
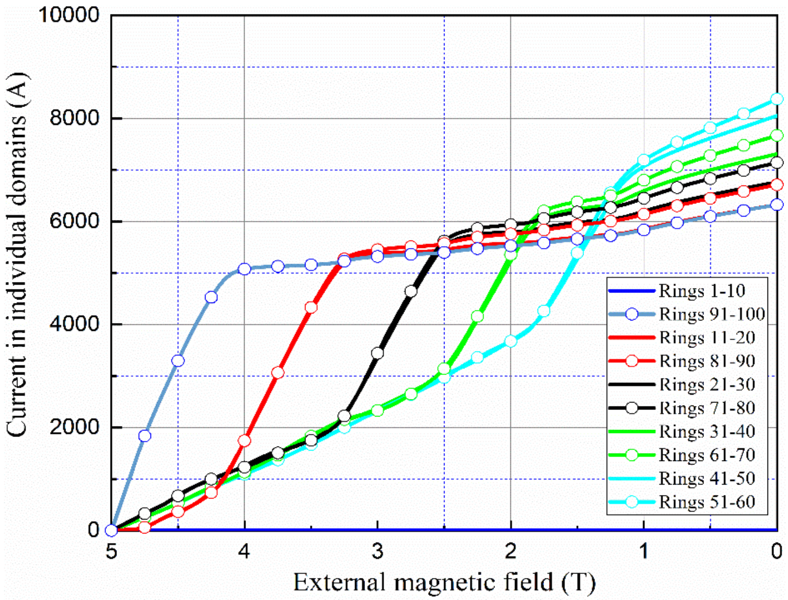


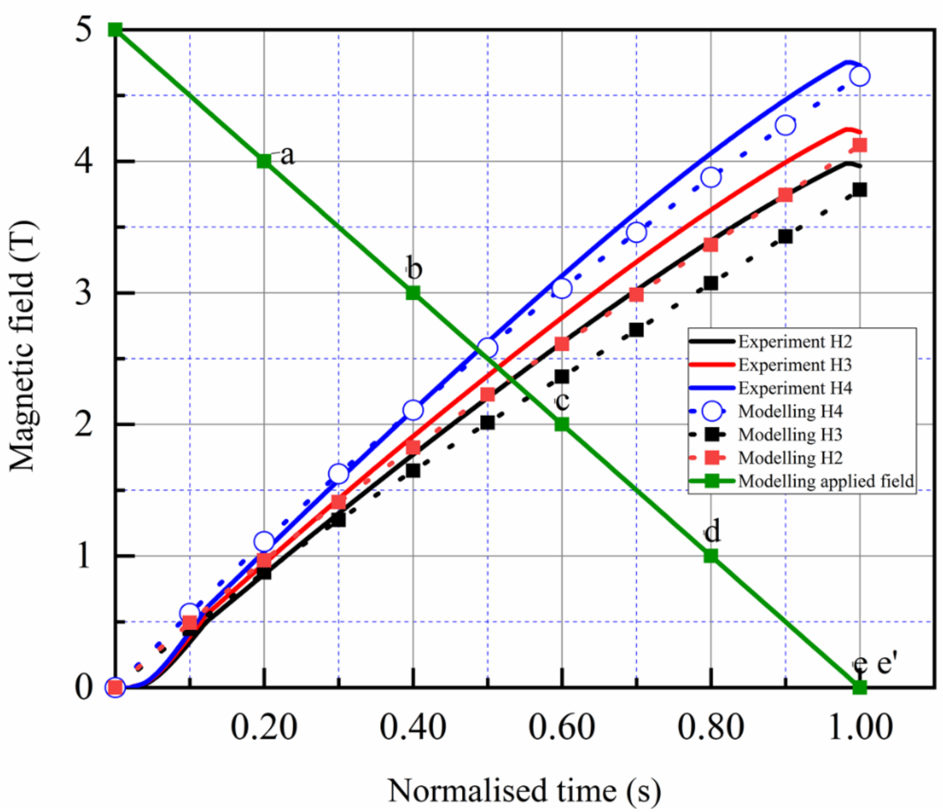
Normalised current density J/Jc

- Ring 1–10 indicates the innermost domain while
- Ring 91–100 indicates the outermost domain



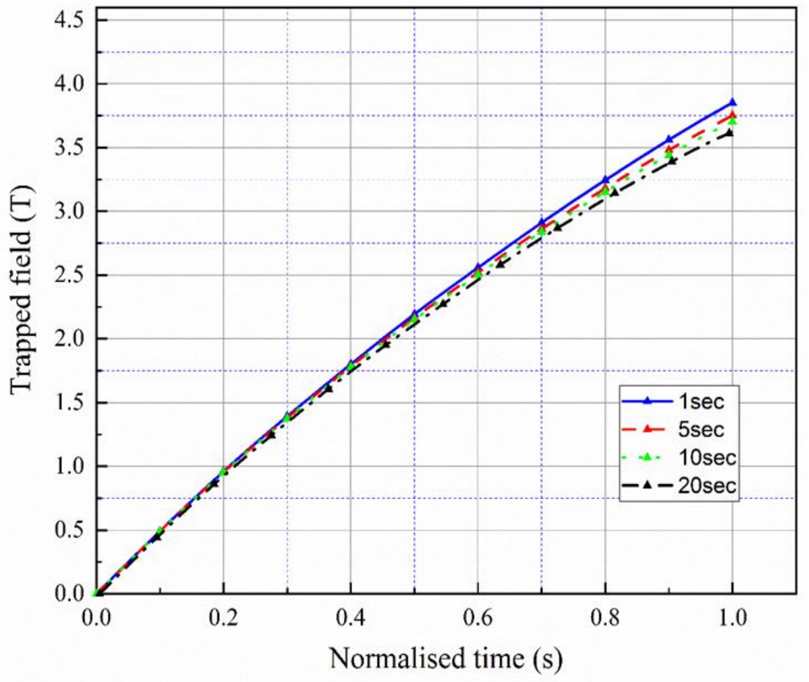
- The recorded current distribution in HTS ring domains were not uniform
- Induced current penetrates from both inner and outer side of the ring magnet simultaneously

2.3 Modelling results

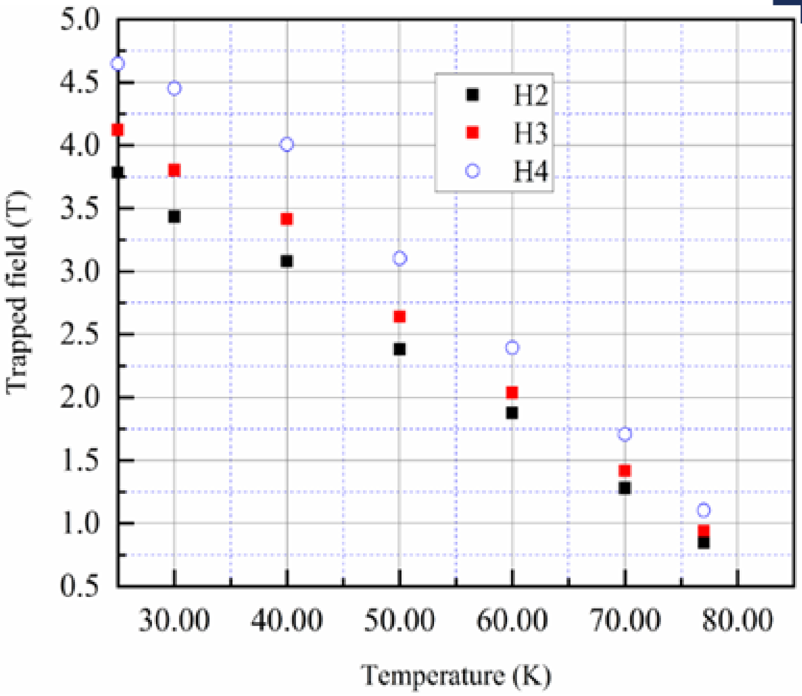


- Simulation result with experiment results.
- Points (a) and (e’) shows the time steps used to show the normalised current distribution.
- The calculation uses a 10-sec ramping rate for the magnetic field.

2.3 Modelling results

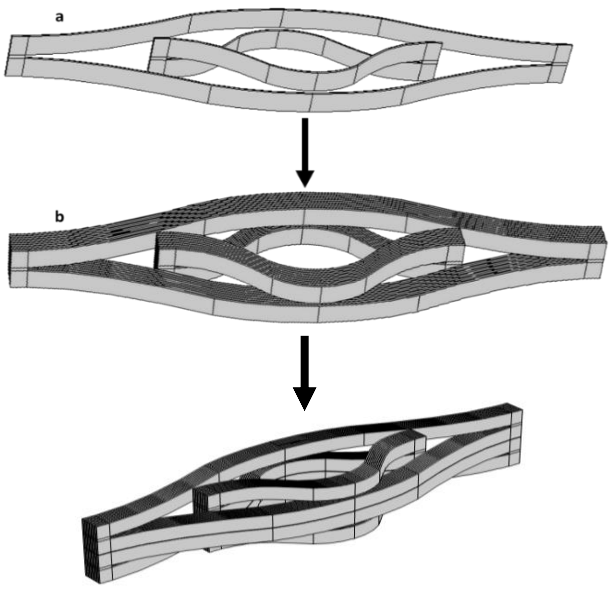


Comparison of the trapped field for four different ramping rates. The curves are for the sensor H3, which is in the middle of the ring magnet.

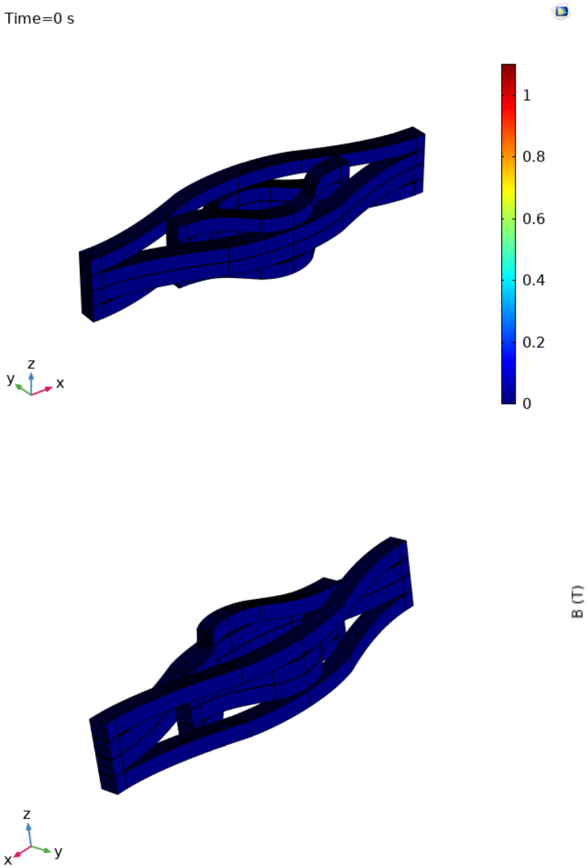


Trapped field of the ring magnet using the field cooling method at various temperatures. H2, H3 and H4 are the sensors at different positions from the centre as already mentioned above.

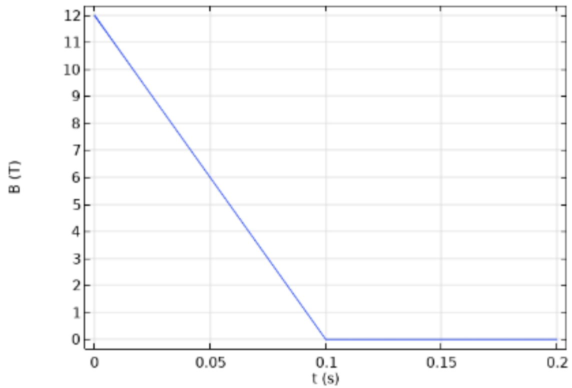
3. Optimized ring magnet design



New optimised ring magnet design



Sample parameters	Value
Inner magnet diameter	23 mm
Outer magnet diameter	160 mm
Operating temperature	4 K
No. of rings	400



3. Optimized ring magnet design

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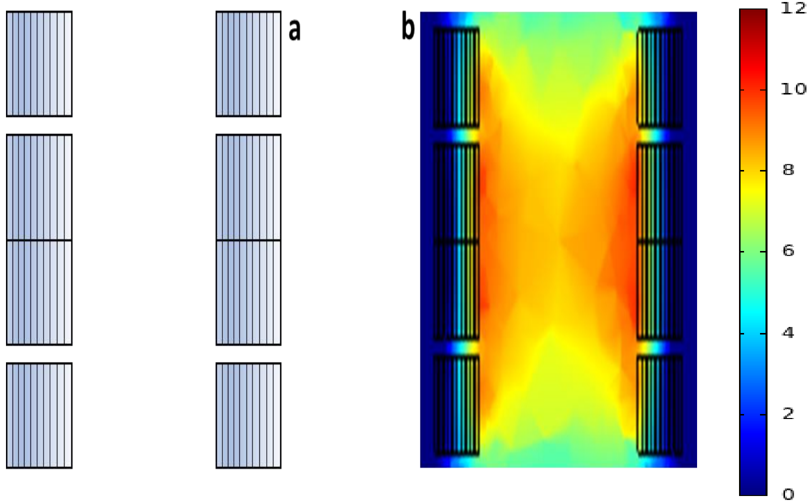
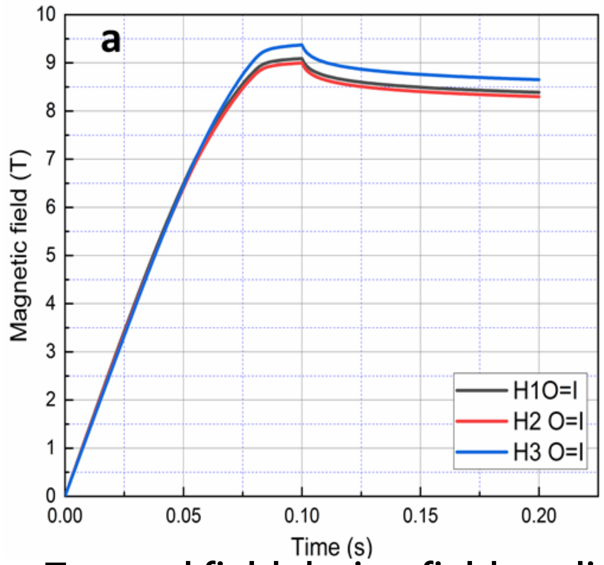


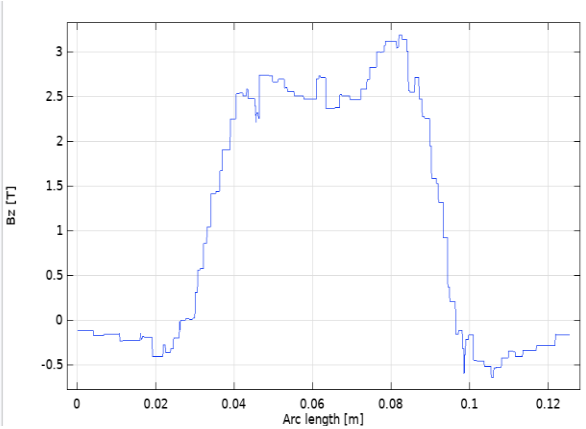
Optimised ring magnet

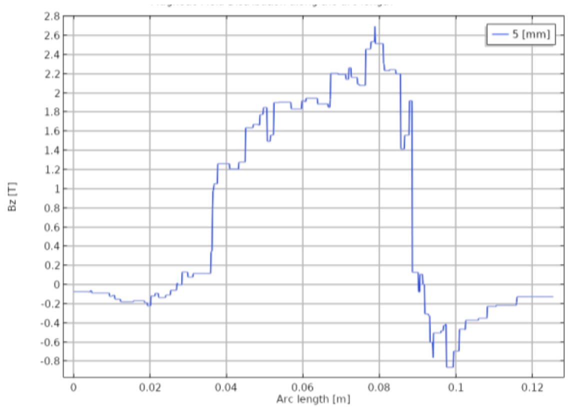


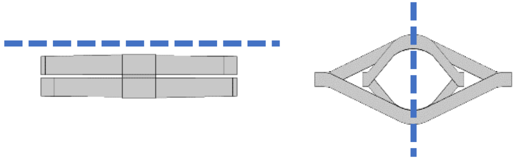
Trapped field during field cooling

- Symmetric field distribution and increased trapped field which is 9.4 Tesla.
- Significant improvement in field homogenization.

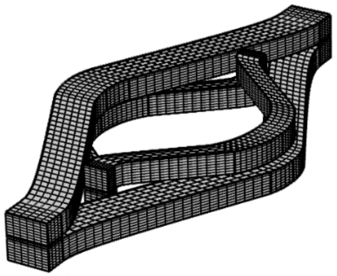
3. Optimized ring magnet design

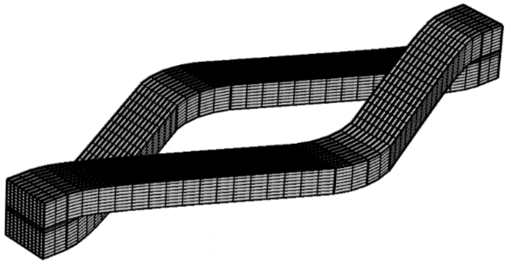






Bz distribution at 5mm above the ring magnet





The field distribution of the optimized ring magnet has more even peak compared with a single ring magnet

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4.Conclusion

- We have demonstrated 4.6 T trapped field for 90 mm HTS ring magnet at 25 K.
- 3D model has been developed to understand the performance of the ring magnet
- Optimised design has been proposed to improve field homogenization.
- Next step is to perform FC and the pulse field magnetization for the optimised HTS ring magnet.

Reference

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Letter

4.6 T generated by a high-temperature superconducting ring magnet

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Abstract

We report here a record 4.6 T trapped field generated by high temperature superconducting (HTS) persistent current loops using a HTS ring structure. By stacking 200 HTS rings into a compact magnet 90 mm in diameter, we performed a field cooling magnetisation at 25 K. The main advantage of the new magnet compared to existing trapped field HTS magnets is that the magnetic field is in the parallel direction to the ab plane of the HTS, leading to higher critical currents in the same magnetic field. Therefore, compact HTS magnets can be developed based on this principle to achieve high magnetic fields. Experimental results show that the final trapped field distribution depends on the ring geometry. We developed a new three dimensional model to simulate the magnetic field distribution within the HTS ring magnet and good agreement between experiments and simulation have been found. The temperature dependency and ramping rate dependency have been studied numerically as potential factors to influence the magnet field. The proposed HTS ring magnet will have promising applications in medical imaging devices, e.g. MRI, as well as electrical machines.

Keywords: high temperature superconducting (HTS) permanent magnets, HTS bulks, HTS stacked tapes, 2G HTS coated conductor, trapped field, H-formulation, field cooling magnetization

(Some figures may appear in colour only in the online journal)

Thank You

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