Mitigating *ab*-plane Critical Current Density Inhomogeneity in Bulk HTS Rings for the Generation of NMR-Grade Magnetic Fields

M. Beck[1], M.D. Ainslie[1]

[1]Bulk Superconductivity Group, Department of Engineering, University of Cambridge

UNIVERSITY OF CAMBRIDGE

BSG

1. Background

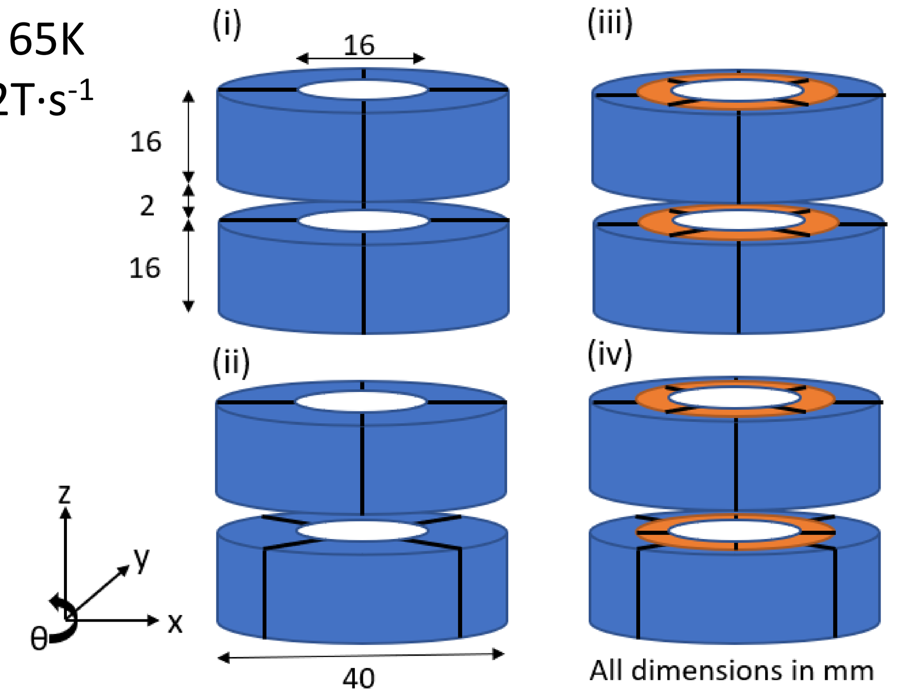
The field trapping ability of high temperature superconducting (HTS) rings make these materials prime candidates to generate the strong, uniform magnetic fields required for nuclear magnetic resonance[1] (NMR). However, fabrication processes such as the top-seed melt growth technique introduce spatial non-uniformity into the superconducting properties of the material – with a higher critical current density (J_c) located at the Growth Sector Boundaries (GSBs) - potentially inducing inhomogeneity into the bore magnetic field[2].

The purpose of this study is to investigate how the relative orientation of Field Cooled Magnetized (FCM) HTS rings within a stack, affects the strength and non-uniformity of the magnetic field within the bore of the stack.

2. Model Set-up

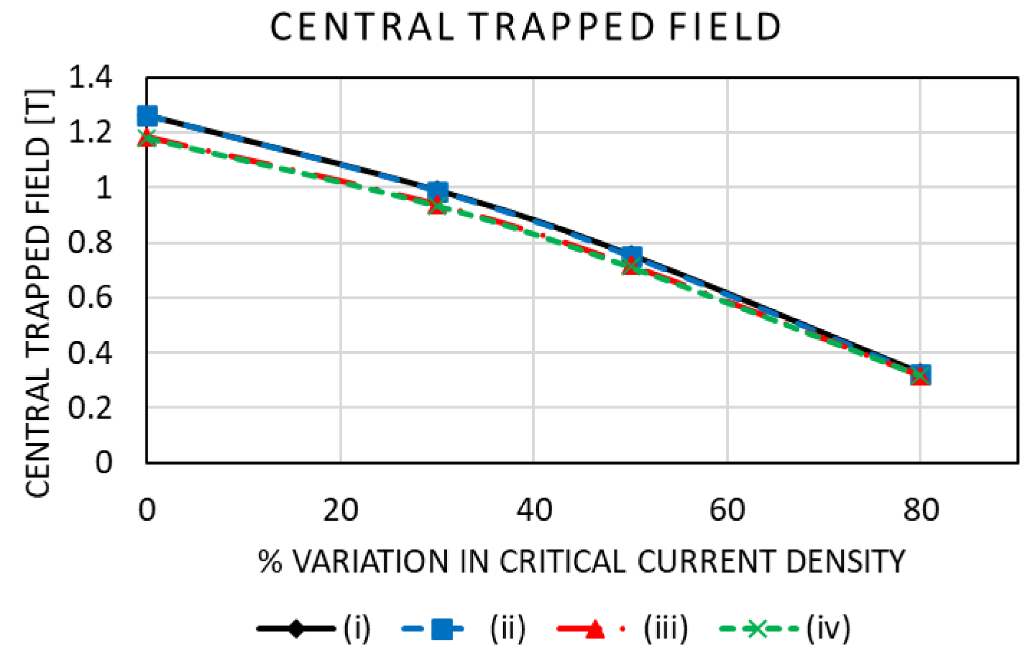
- 3D Model based on H-formulation built in COMSOL® 5.6
- Non-uniform critical current density (J_c) modelled as axially uniform, with spatial dependence in sample *ab*-plane following
  - $J_c = 2.16 \times 10^8 \left[\frac{A}{m^2}\right] \cdot \frac{1}{1+\frac{B}{1.3\,[T]}} \cdot \left(\left(100 - \frac{\beta}{2}\right) + \frac{\beta}{2}.\sin(4\theta + \phi)\right)$

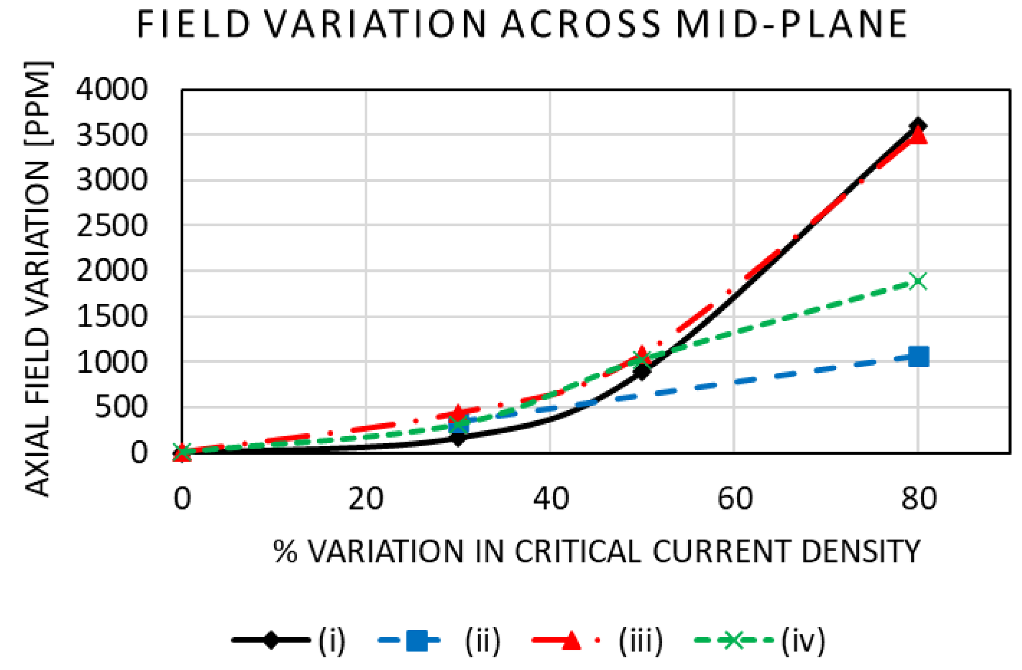
  where β is the relative reduction in J_c such that the peak J_c is constant, and ϕ is the offset angle relative to the x-axis of the model
- Magnetised by FCM from 2T at 65K with constant ramp rate of 0.02T·s^{-1}
- 4 cases considered:
  i. 2 rings with GSBs aligned
  ii. 2 rings with GSBs offset (ϕ = 0 for the top ring, $\frac{\pi}{4}$ for the bottom ring)
  iii. 2 pairs of rings with GSBs offset within the plane and aligned axially
  iv. 2 pairs of rings with GSBs offset both within the plane and axially

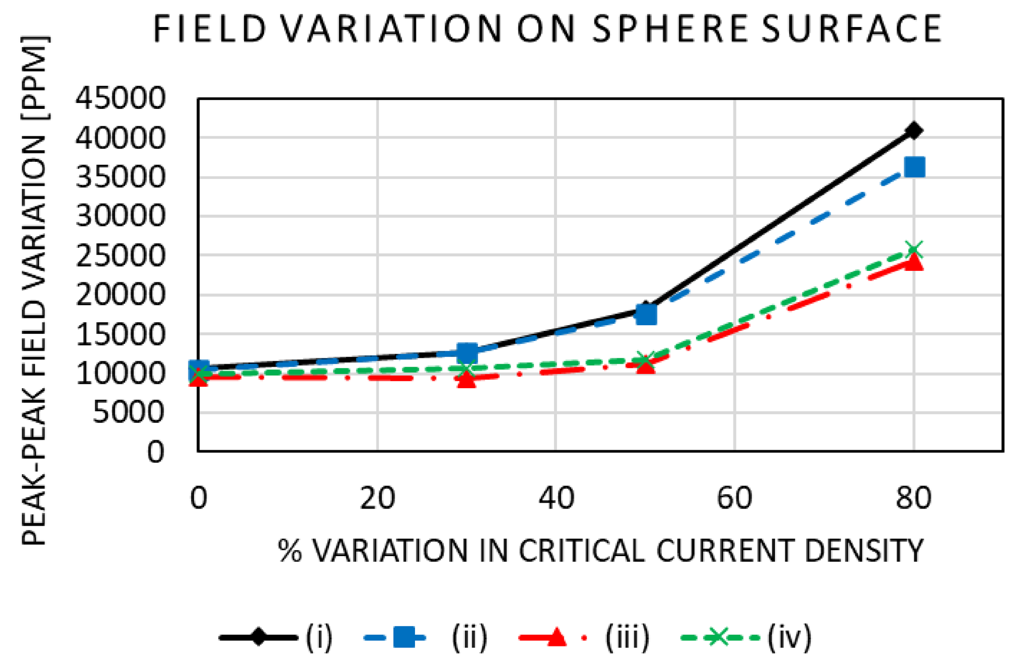


- Spherical harmonics calculated, using PySHTools[3], for the surface of a sphere with 4 mm radius at the centre of the bore

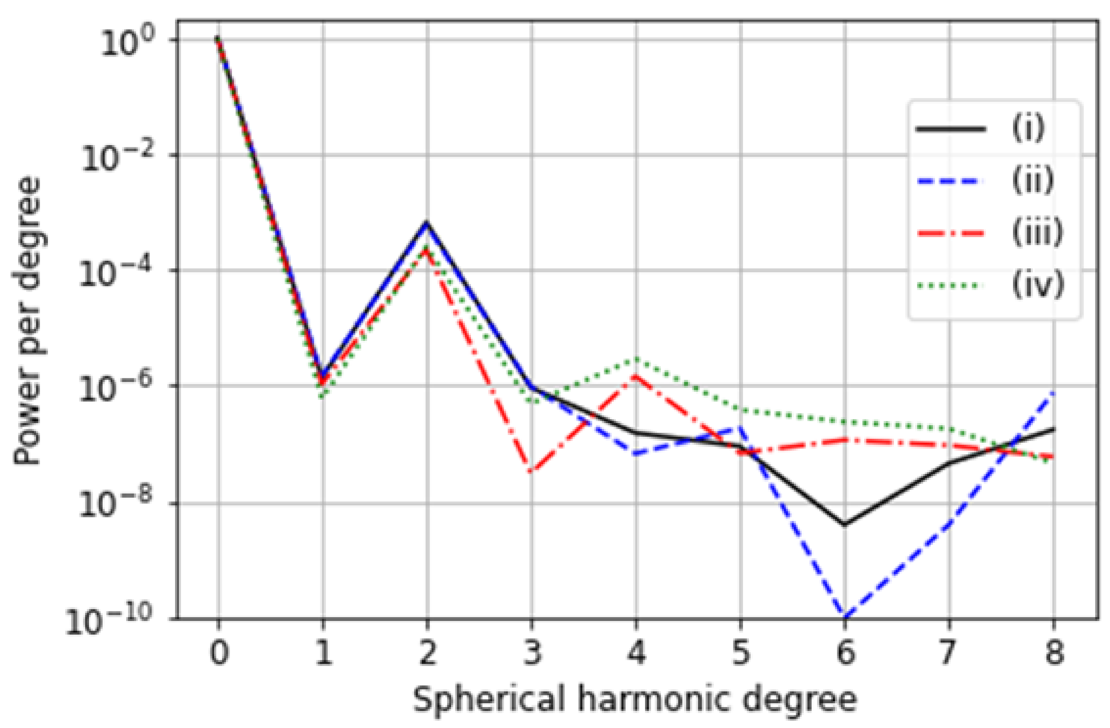
3. Results and Discussion



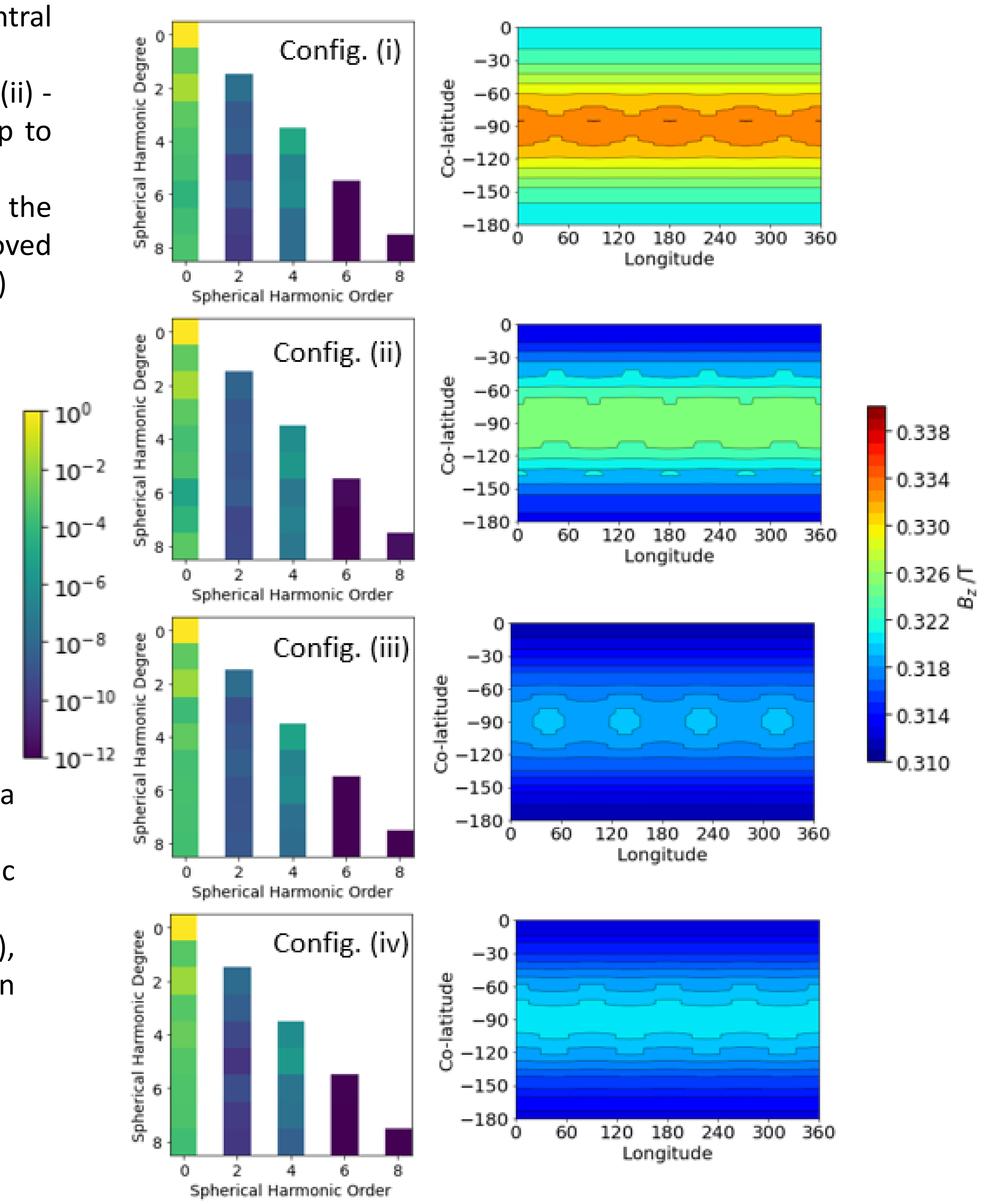




- The relative orientation of rings within the stack has minimal impact on the central trapped field strength
- Arranging a single pair of rings such that the GSBs are offset axially - configuration (ii) - reduces the peak-peak variation in the magnetic field across the mid-plane by up to 65% and on the surface of the spherical imaging volume by up to 10%
- Using 2 pairs of rings improves the peak-peak field variation on the surface of the spherical imaging volume by up to 75%, but the mid-plane variation is not improved relative to configuration (i) when the rings are axially aligned, as in configuration (iii)



- The average normalised harmonic power is reduced by offsetting the GSBs within a single pair of rings, and using 2 pairs of rings
- Using 2 pairs of rings suppresses the harmonic content for all orders for harmonic degrees < 4
- The higher order harmonics are most strongly suppressed using configuration (iv), whilst the 2nd order harmonics are enhanced using configuration (iii) – configuration (iv) therefore simplifies the shimming requirements for practical NMR fields



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