UNIVERSITY OF BATH

HTS MODELLING 2016

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An efficient 3D FEM model based on T-A formula for superconducting coated conductors

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Outline

- Introduction
- Methodology
- Validation
- Application
  - TSTC coil
  - Racetrack coil
  - Reobel cable

Introduction

- Why do we need 3D models for 2G HTS?

  - Assembled 2G HTS cables for high current applications
  - 3D modelling is crucial to guide design and optimisation

- Existing models for 3D FEM calculation:
  - *A* formula
    - ✓Convenient to implement (FlexPDE)
  - *H* formula
    - ✓Convenient to implement (COMSOL)
  - *T* formula
    - ✓Easy to impose transporting current

Challenges

- Current challenges facing large scale 3D modelling:
  - High aspect ratio
  - Complicated geometry ➡ Extremely time consuming
  - Non-linear *E*-*J* power law

- Can we combine the advantages of exiting formula to address the challenges?
  - Easy to implement in FEM software
  - Easy to impose boundary conditions
  - Computationally efficient

YES, *T* - *A* formula

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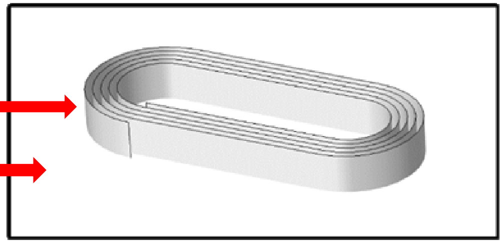
T-A formula

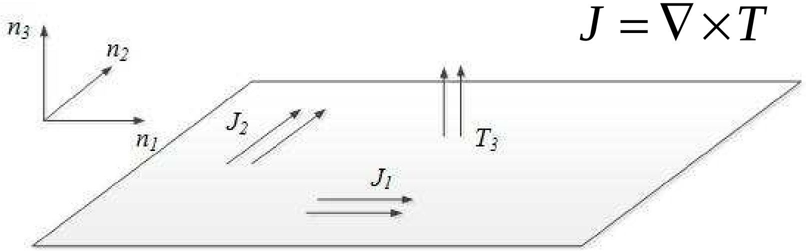
- Geometry
  - HTS sheet
  - Air space



- Two assumptions
  - Sheet approximation
  - Ignore the parallel magnetic field component

- State variables
  - ***T*** (current vector potential) normal to **Superconducting sheet**
  - ***T*** is also denoted as ***g*** in some other papers
  - ***A*** in **Air space**

$$J = \nabla \times T$$



Governing equation

***T* – *A* formula**

$$\nabla \times E \cdot \vec{n} + \frac{\partial B \cdot \vec{n}}{\partial t} = 0$$

$$J = \nabla \times T$$

$$J = \begin{cases} T_z \cdot \vec{n}_y - T_y \cdot \vec{n}_z \\ T_x \cdot \vec{n}_z - T_z \cdot \vec{n}_x \\ T_y \cdot \vec{n}_x - T_x \cdot \vec{n}_y \end{cases}$$

$$E = E_0 \left(\frac{|J|}{J_c} \right)^n \frac{J}{|J|}$$

Superconducting sheet

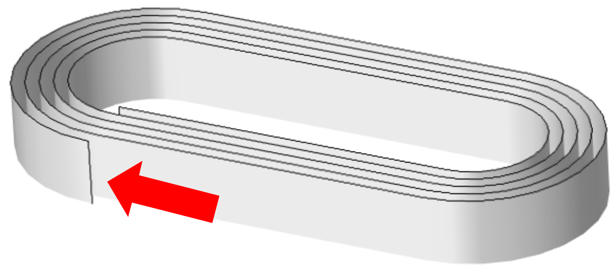
$$B = \nabla \times A$$

$$\nabla \times \nabla \times A = \mu_0 J$$

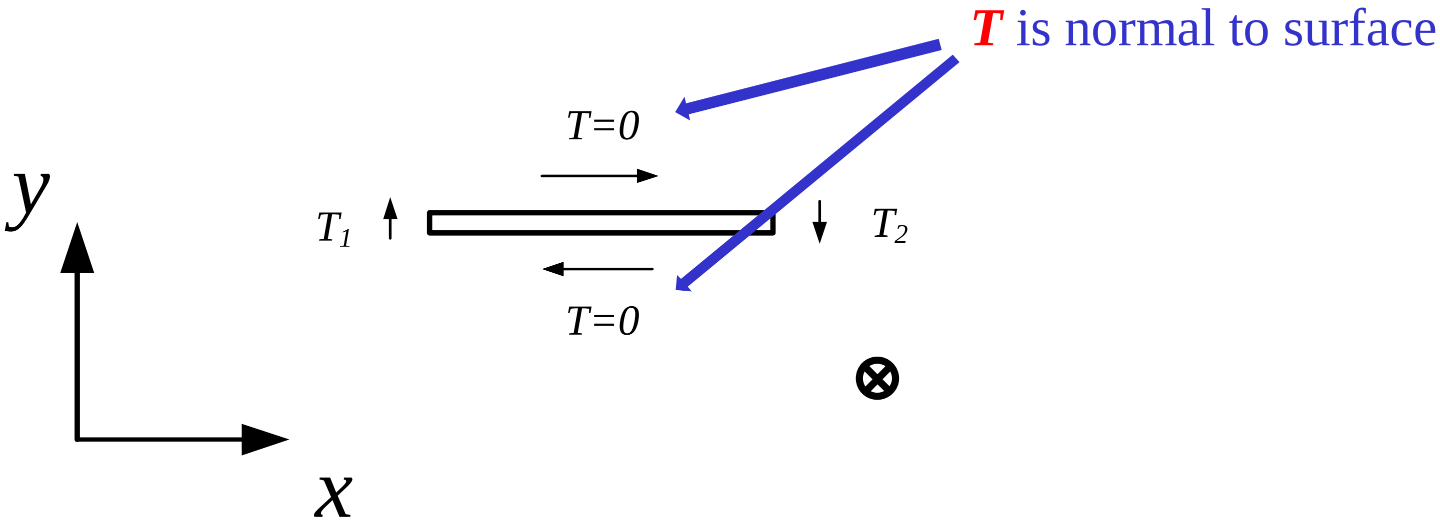
Air space

Imposing current

$$I = \int JdS = \int \nabla \times TdS = \oint Tds$$



$$I = (T_1 - T_2)d$$



1. Nii M, Amemiya N and Nakamura T 2012 *Superconductor Science and Technology* **25** 095011 ISSN 0953-2048

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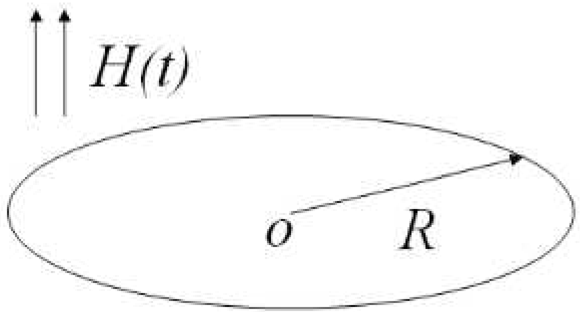
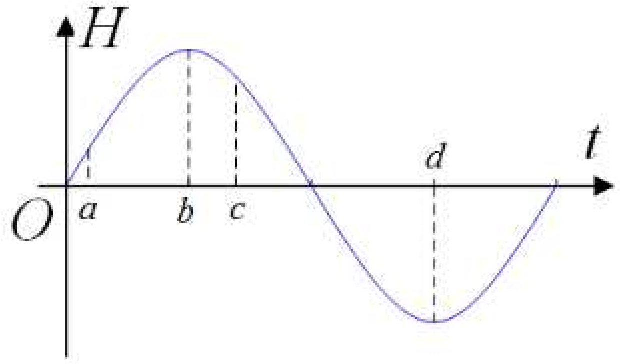
Validation

- Magnetisation of thin disk
  - Dimension: R=10mm, thickness d =1μm
  - n=201, $J_c = 10^{10}$A/m^2
  - $H_c = J_c d$
  - $T=0$ on the boundary of the disk

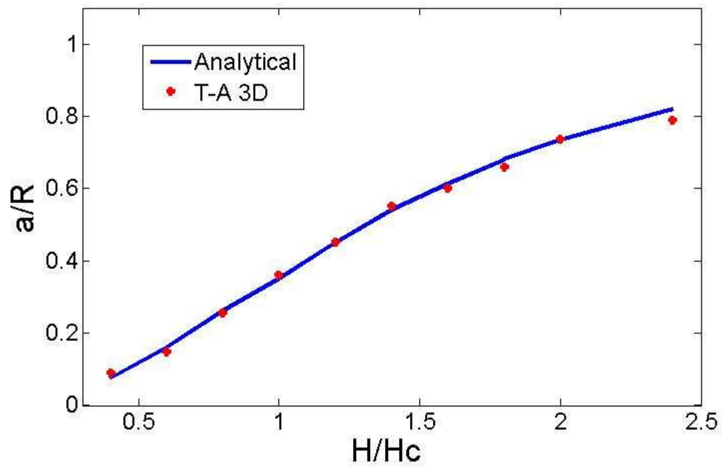


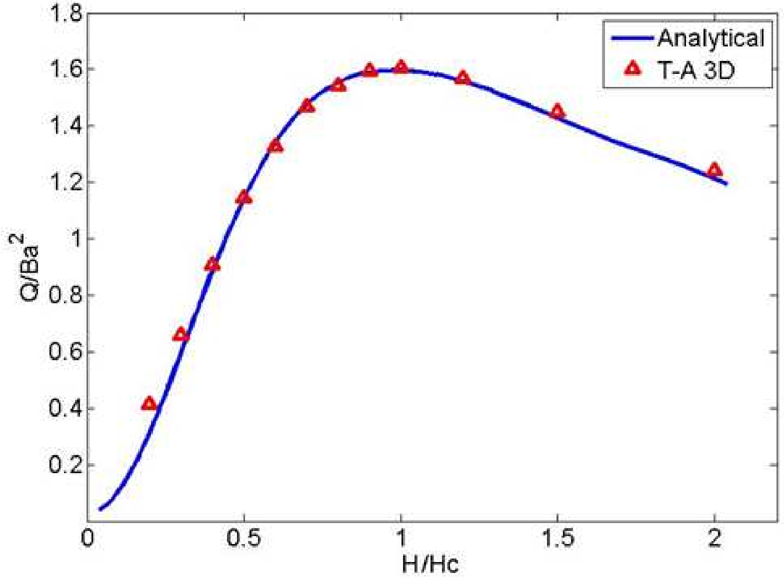


Validation

- Penetration depth & normalized magnetisation loss

$$\frac{a}{R} = 1 - \frac{1}{cosh(H/H_c)}$$





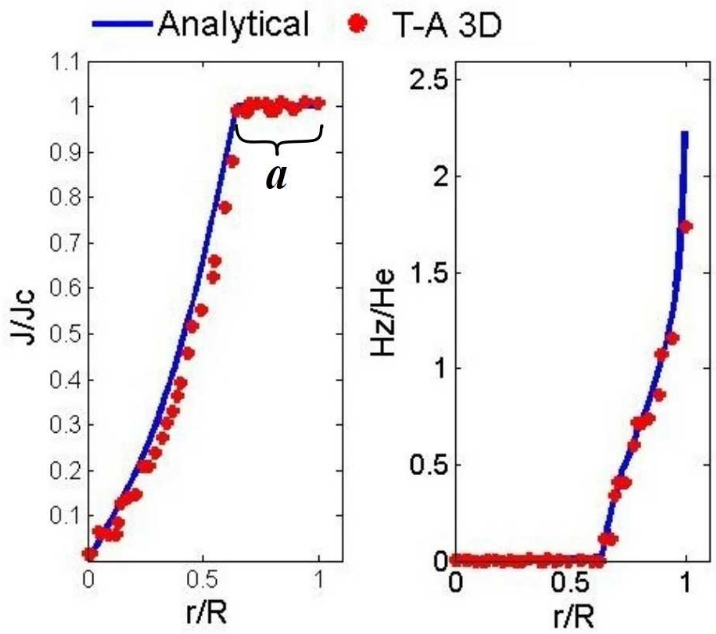
1. Mikheenko P and Kuzovlev Y E 1993 *Physica C: Superconductivity* **204** 229–236

2. Clem J R and Sanchez A 1994 *Physical Review B* **50** 9355

Validation

- Current and field along radius direction

$$I(r)=\begin{cases} J_c\frac{2}{\pi}atan\left[\frac{r}{R}\left(\frac{R^2-a^2}{a^2-r^2}\right)^{1/2}\right] & ,r<a \\ J_c & ,r\geqslant a \end{cases}$$



$H = H_c$

1. Mikheenko P and Kuzovlev Y E 1993 *Physica C: Superconductivity* **204** 229–236

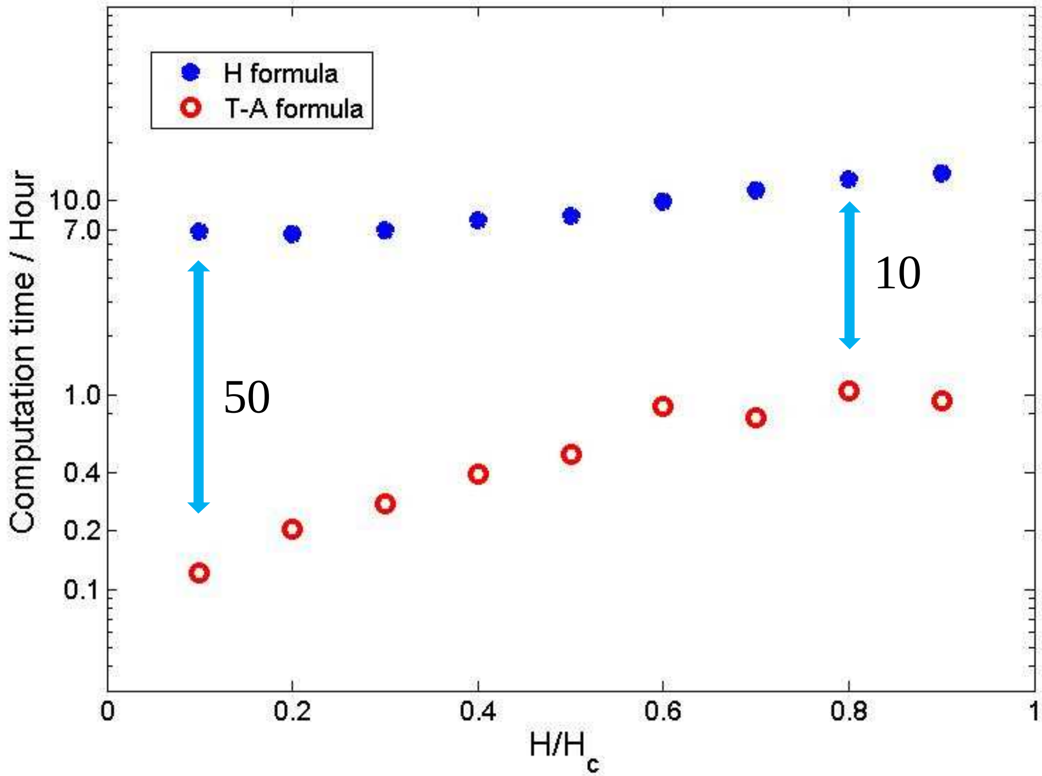
2. Prigozhin L 1998 *Journal of Computational Physics* **144** 180–193

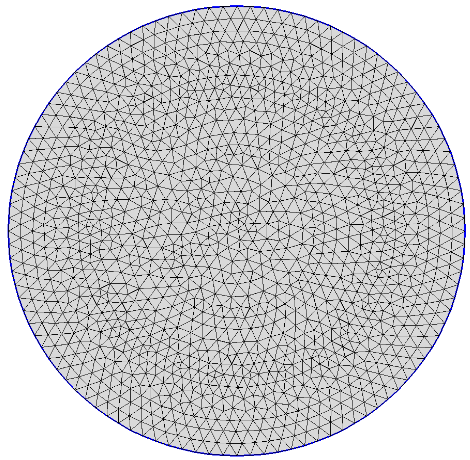
Validation

- Efficiency

CPU: Intel i5 2400
Memory: 8 GB

Formula	*H*	*T-A*
Thickness	10μm	1μm





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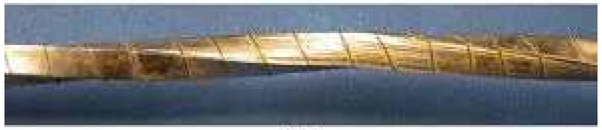
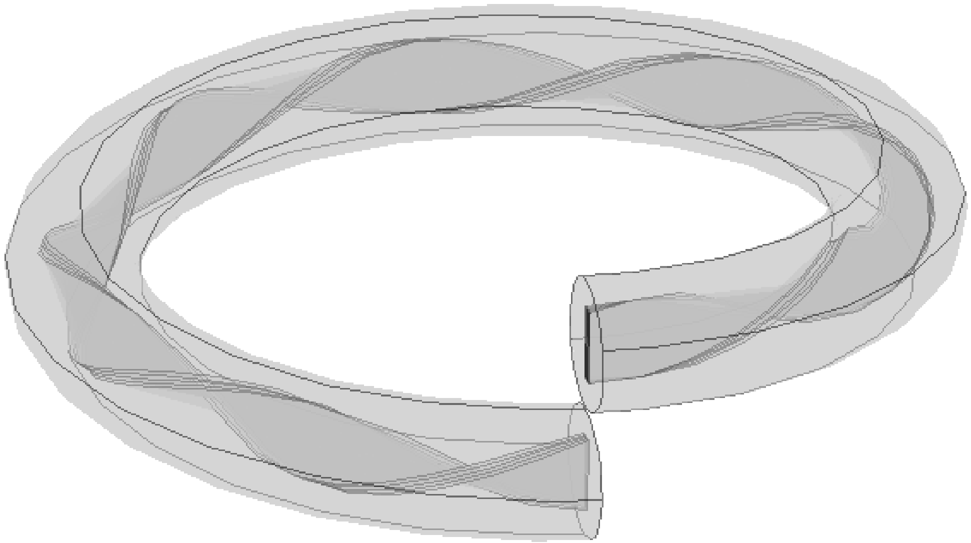
Application-TSTC coil

5 strands TSTC cable coil

(a)



(b)

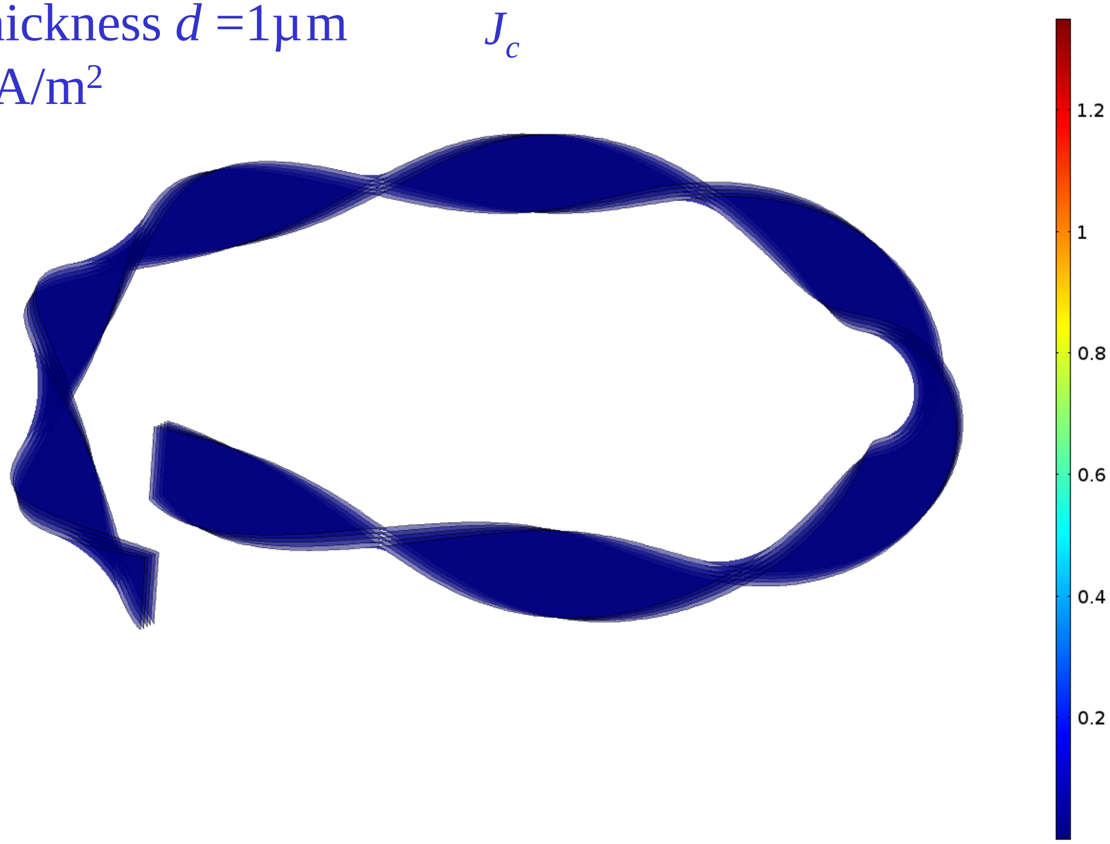


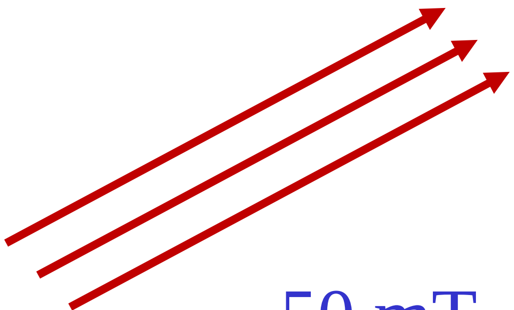
Application-TSTC coil

- Magnetisation
  - ➢ width=5mm, thickness d =1μm
  - ➢ n=21, $J_c = 10^{10}$A/m^2

$$\frac{|J|}{J_c}$$

3 hours

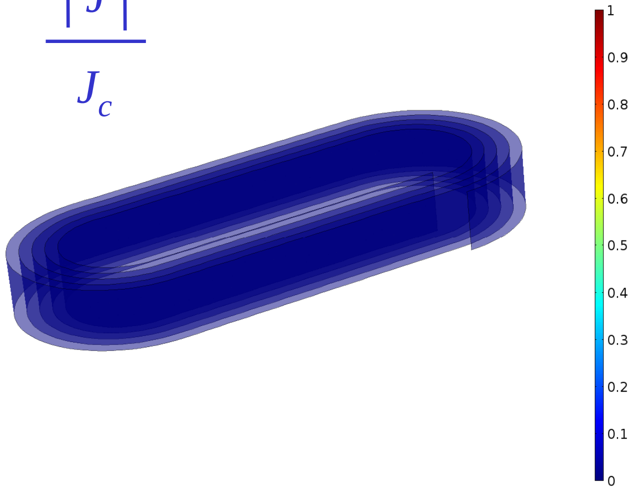




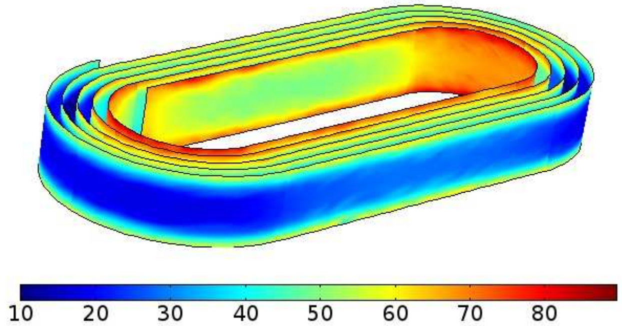
50 mT, 50 Hz

Application-Racetrack coil

$$\frac{|J|}{J_c}$$

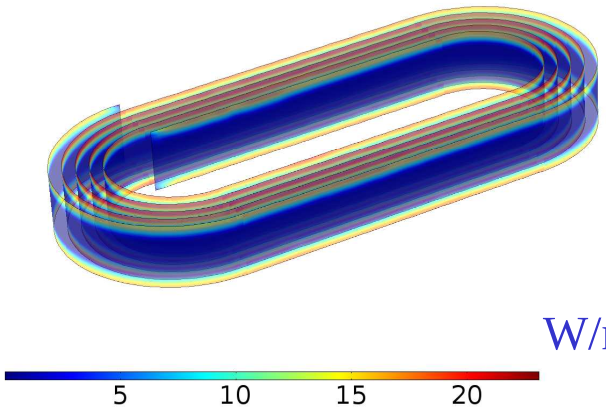


$|B|$



mT

AC loss

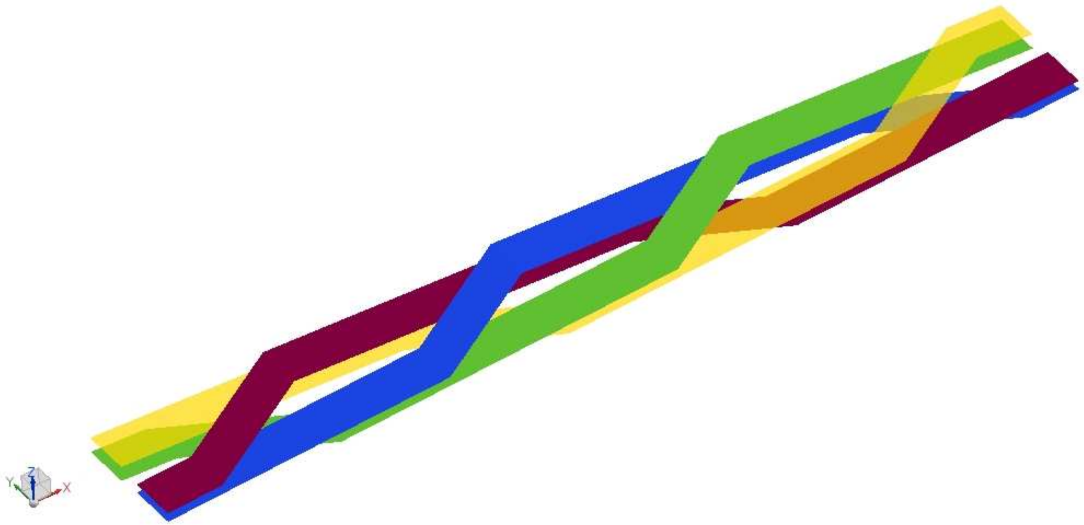


W/m^2

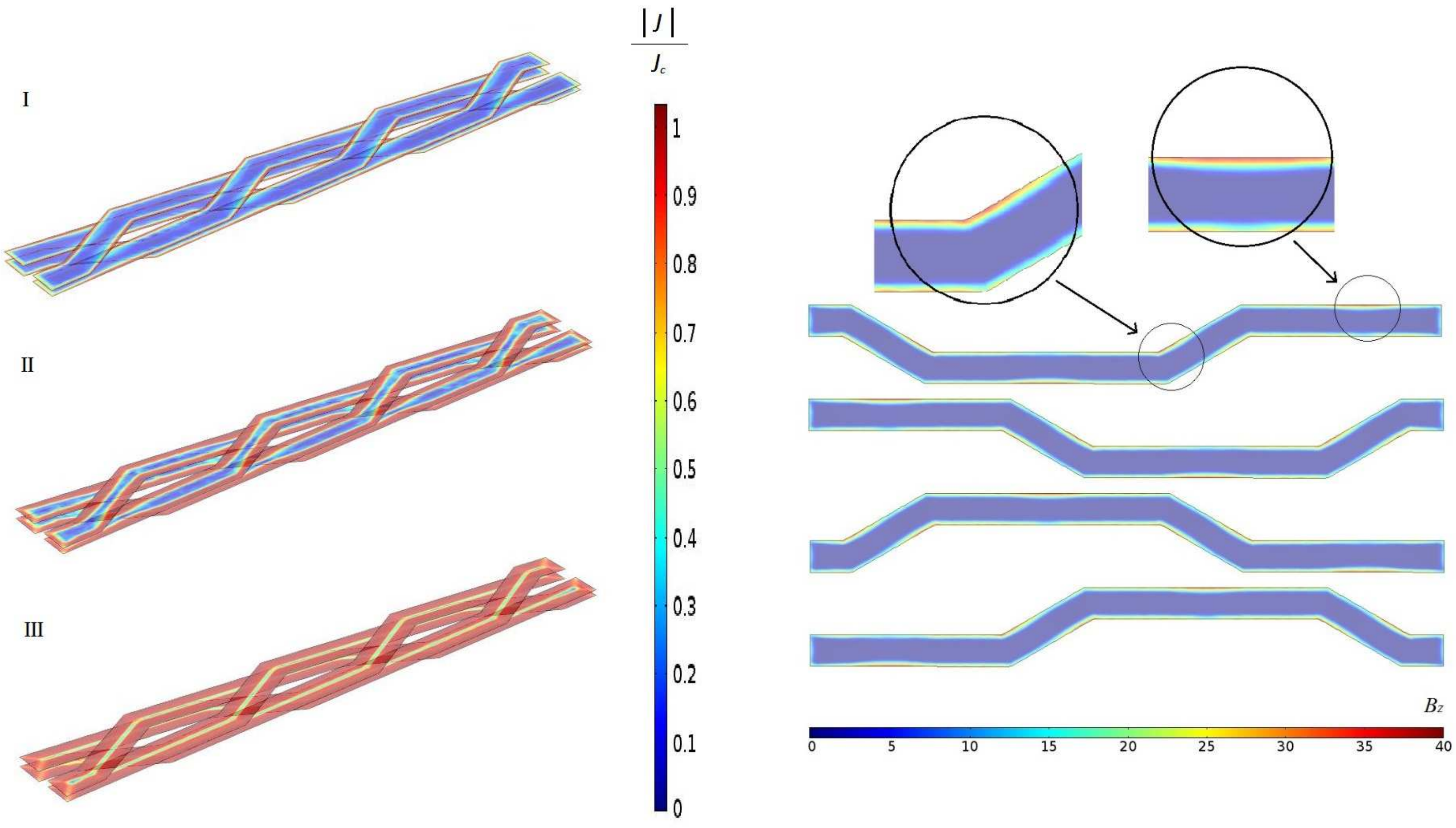
- Current can be applied in complex geometry
- Current distribution, magnetic field and loss can be calculated

Application-Roebel

- Magnetisation of a full pitch Roebel cable
  - Dimension: length = 40mm, thickness d =1μm
  - n=21, $J_c = 10^{10}$A/m^2



Application-Roebel



20 mT, 50 Hz

Conclusions

- A new 3D FEM is presented
- Validated by analytical and FEM results
- Very efficient compared with existing models
- A powerful tool to model assembled 2G HTS cables and magnets

Thank you for your attention!
Any questions?

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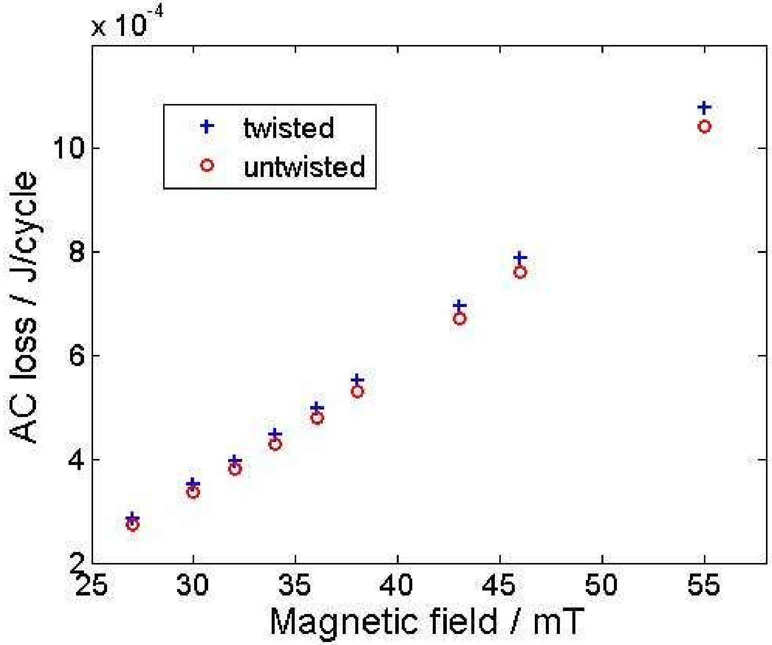
Application-Roebel



twisted > untwisted

shielding in untwisted