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Design of non-planar coils with REBCO tapes for use in superconducting rotating electrical machines

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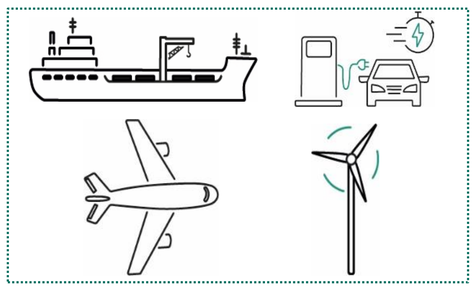
Introduction

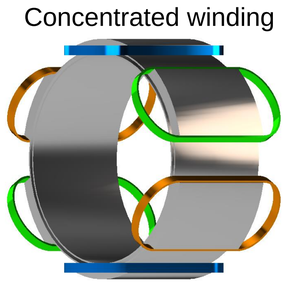
Potential applications



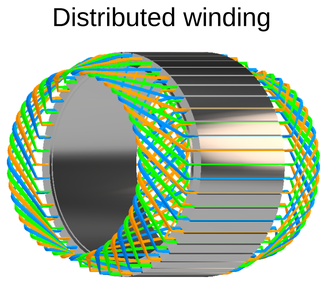
- High-power-density superconducting machines envisioned for future energy applications.

Two winding configurations

Concentrated winding



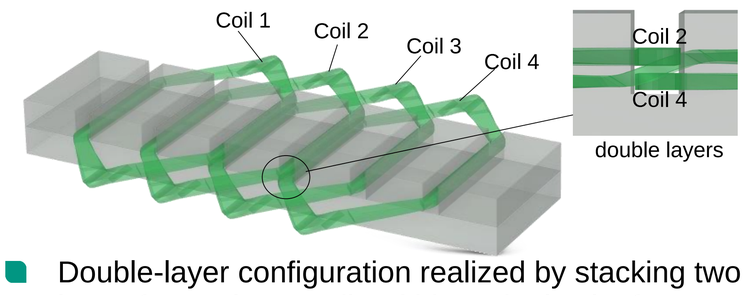
Distributed winding



- Distributed winding layout based on non-planar REBCO coils implemented, enabling higher space utilization and reduction of harmonics.

Double-layer distributed winding

stator slot with double-layer configuration

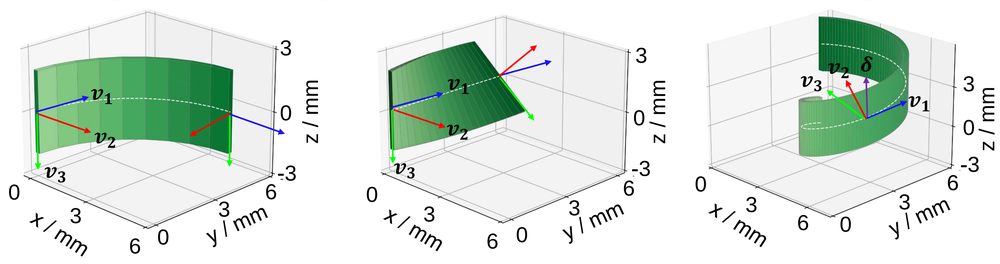


- Double-layer configuration realized by stacking two legs of non-planar coils within a single slot for more higher space utilization.

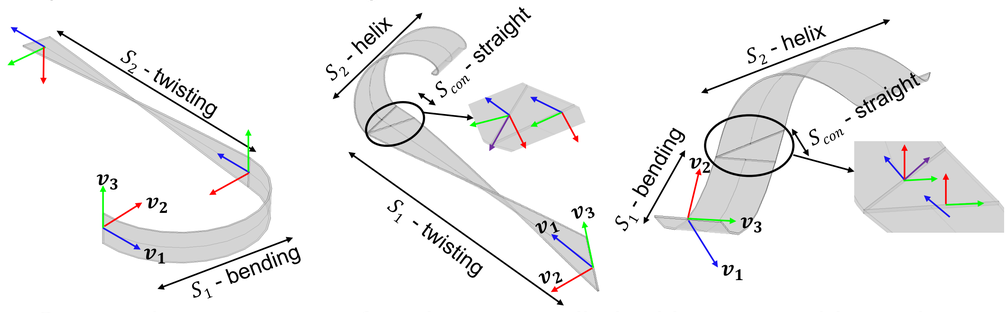
Coil shape design: segmentation method

Segmentation method

Step 1: geometry modelling of basic segments (easy-way bending, twisting, helix)



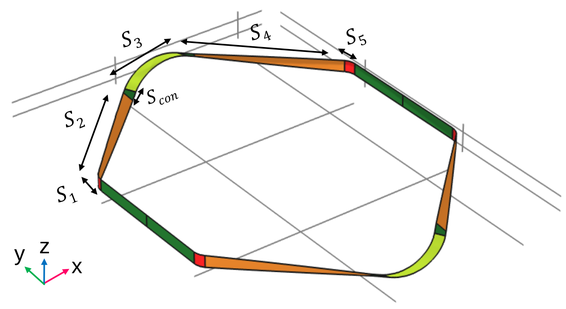
Step 2: connection between segments



- Geometric parameters of each segment limited by acceptable strain
- Boundary conditions defined to ensure smooth connections

Double-layer winding coil sample

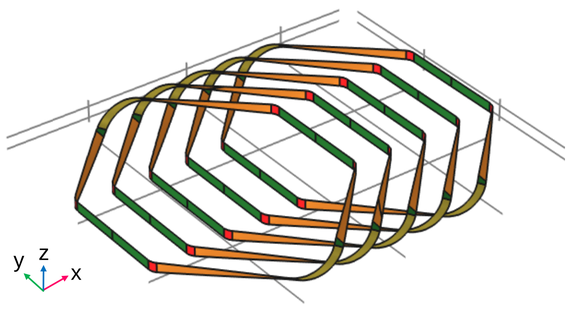
Shape of the non-planar coil for double-layer winding



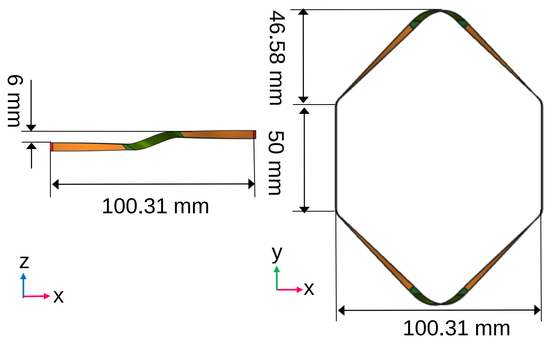
Design parameters of each segment

parameter	value
S_1 - bending: radius / angle	5 mm / 45°
S_2 - twisting: length / angle	50 mm / 50°
S_{con}: length	2 mm
S_3 - helix: radius / pitch	8.92 / 42.92 mm
S_3 - helix: parameter range	[0.47rad, 2.67rad]
S_1: strain limit	0.5%
S_2 & S_3: strain limit	0.2%

5 coils arranged horizontally (18 mm spacing)



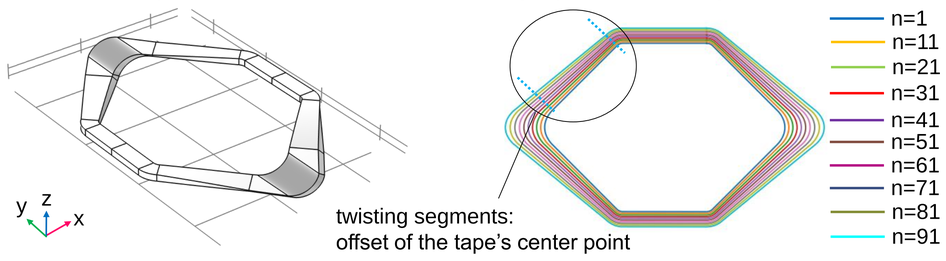
Dimension of the coil



Coil realization: multi-turn design, fabrication and testing

Multi-turn coil geometry

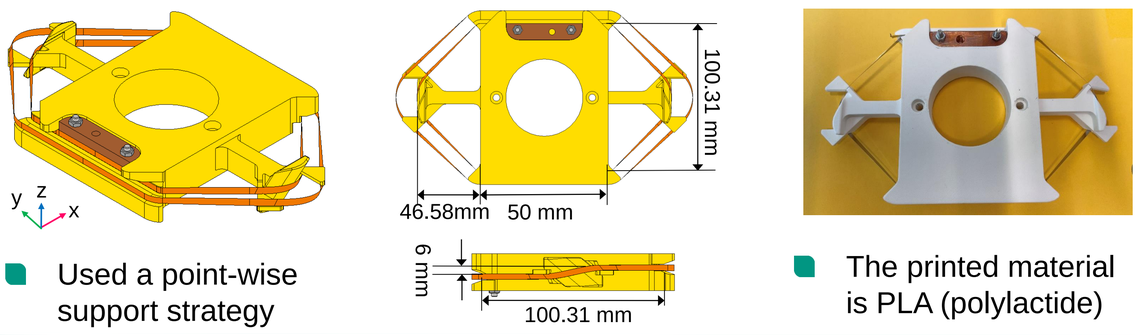
Model of non-planar coil with 91 turns and its projection on XY plane



- Each turn has a controlled trajectory to manage position and strain.

Support structure

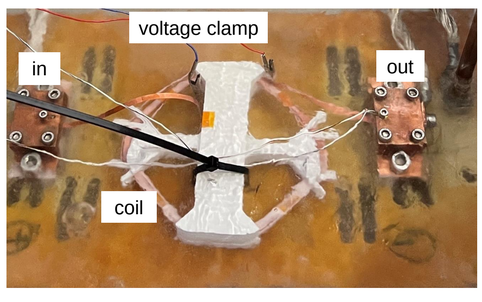
3D printed, strain-controlled support structure for the non-planar double-layer winding coil



- Used a point-wise support strategy
- The printed material is PLA (polylactide)

Critical current measurement setup

Setup for testing the coil in liquid nitrogen



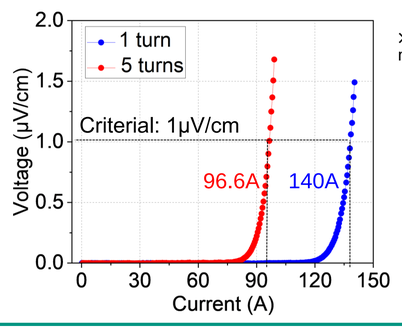
Main properties of REBCO tape

Superconductor	
Manufacturer	Superpower
Width	4.01 mm
Thickness	0.094 mm
I_c Average/minimum	146 A / 142 A
Thickness of HTS layer	1 µm
Thickness of substrate	50 µm

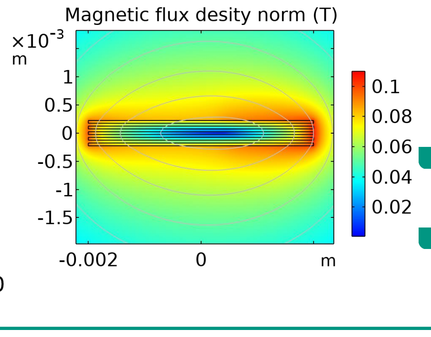
Experimental and simulation results

Note: $J_c(B,\theta)$ used in 2D model comes from database built by the team at Robinson

$I_{c,exp}$: experimental results (77K)



$I_{c,sim}$: 2D FEM model (COMSOL)



I_c results

turns	$I_{c,exp}$ (A)	$I_{c,sim}$ (A)
1	140	140.31
5	96.6	102.56

- I_c dropped mostly due to self-field, not 3D shape
- Small deviations from I_c-B variation

Conclusion & outlook

- First proposal and design of segmented non-planar REBCO coils in HTS double-layer distributed-winding for rotating machine
- Segmentation method offers a generalizable approach for non-planar REBCO coils design
- Structural optimization achievable by adjusting the parameters of each segment
- Ongoing work includes automated winding and electromagnetic performance analysis

Acknowledgments
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