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Comparison of 2D simulation models to estimate critical current of a superconducting coil

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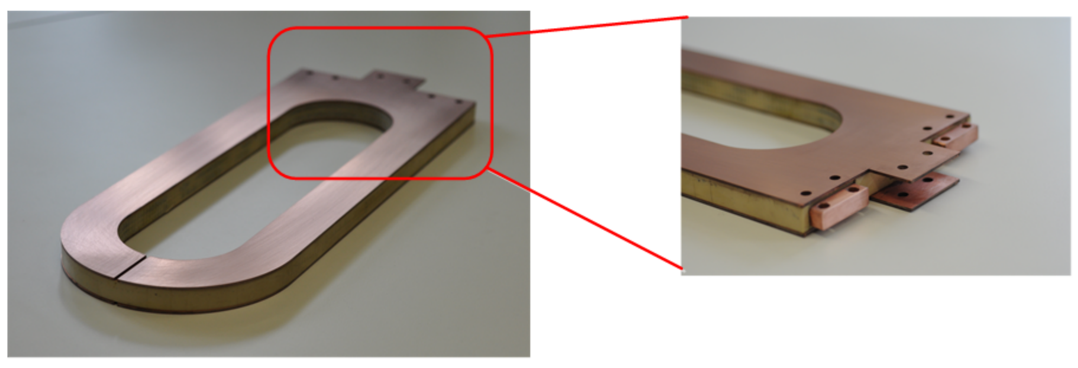
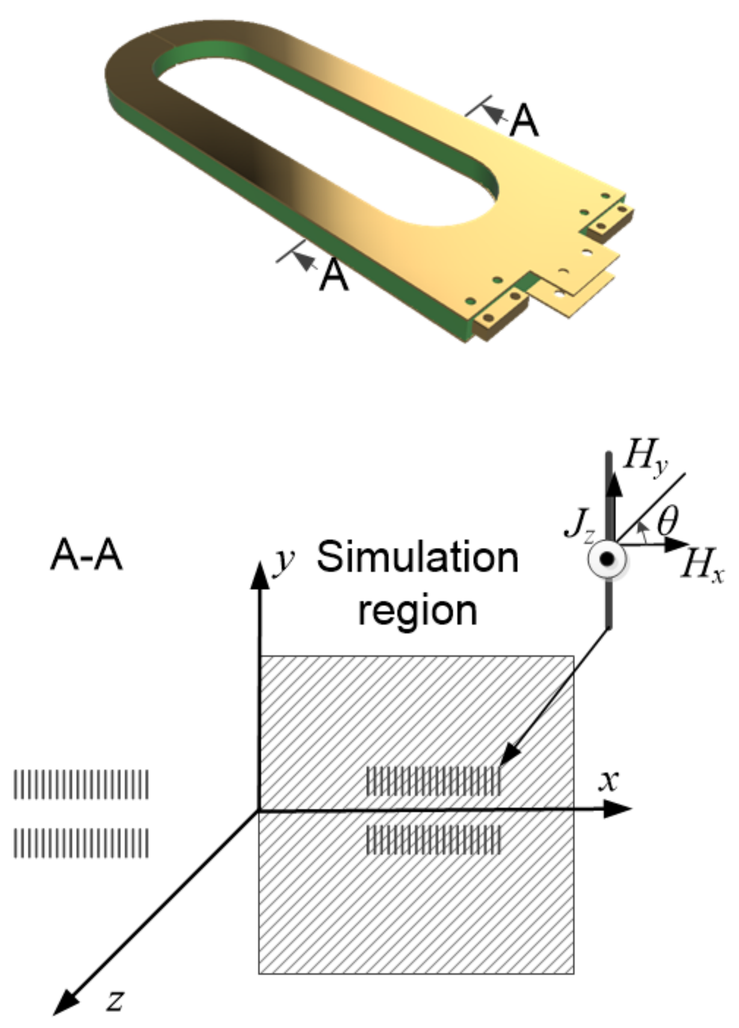
Motivation



- Review available numerical models of superconducting (SC) coils
- Compare results of simulations and measurement in the case of a SC coil with more than 200 turns
- Provide readers with a general idea on how to estimate critical current of a SC coils for power devices

Model theory



***H*-formulation** $\nabla\times\boldsymbol{H}=\boldsymbol{J}$ $\nabla\times(\rho\boldsymbol{J})=-\frac{\mu_0\partial\boldsymbol{H}}{\partial t}$

- The governing equations of *H*-formulation are Ampere's law and Faraday's law and state variable is magnetic field ***H*** [1],[2]

***T-A* formulation** $\nabla\times(\rho(\nabla\times\boldsymbol{T}))=-\frac{\partial(\nabla\times\boldsymbol{A})}{\partial t}$ $\nabla\times\left(\frac{\nabla\times\boldsymbol{A}}{\mu_0}\right)=\boldsymbol{J}$

- *T-A* formulation is based on thin strip approximation and two state variables: current vector potential ***T*** in SC layers and magnetic vector potential ***A*** in the whole area [3]

***P*-model** $\boldsymbol{J}=\boldsymbol{J}_c(B_x,B_y)P$ $\nabla\times\left(\frac{\nabla\times\boldsymbol{A}}{\mu_0}\right)=\boldsymbol{J}$

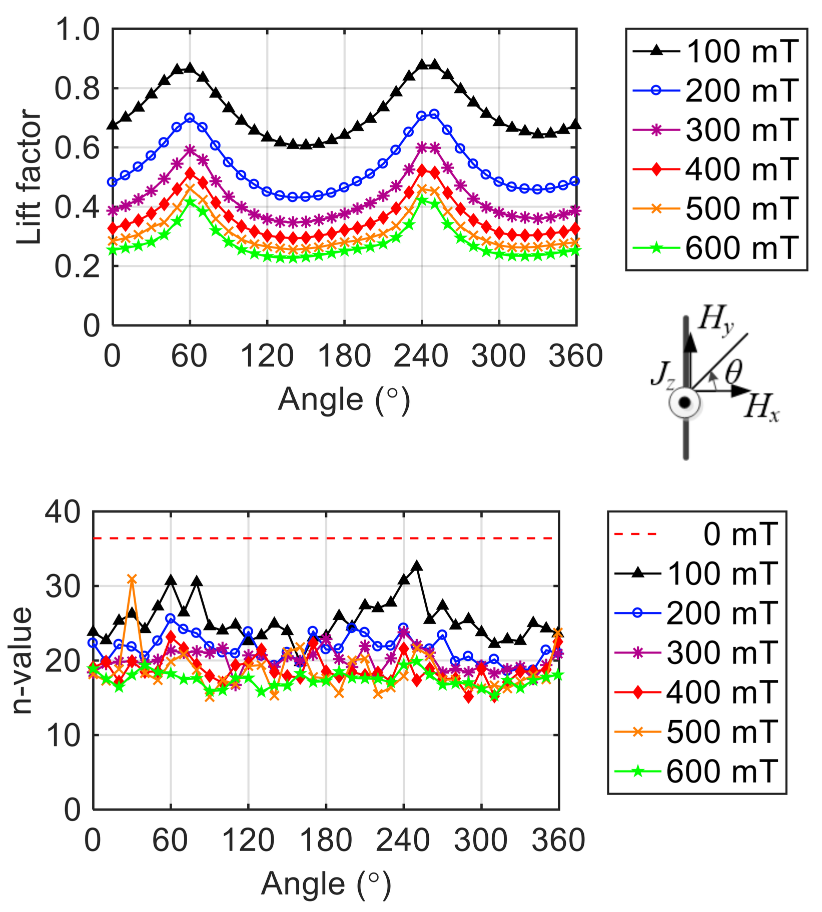
- The so called *P*-model is based on the asymptotic limit of Faraday's equation when *t* approaches to infinity [4]

Load-line method $\nabla\times\left(\frac{\nabla\times\boldsymbol{A}}{\mu_0}\right)=\boldsymbol{J}$

- The load-line method is implemented by calculating the magnetic field at a give current and by comparing it to the expected critical current of the tape at that field [5]

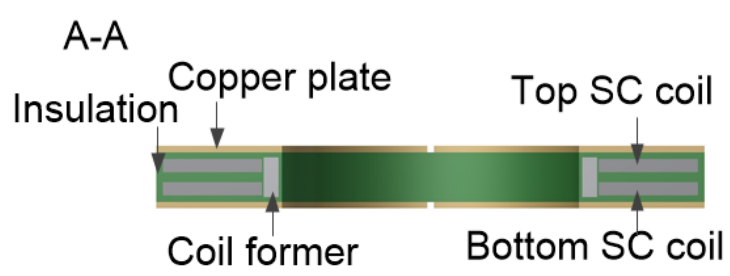
Experiment

Anisotropy of tape



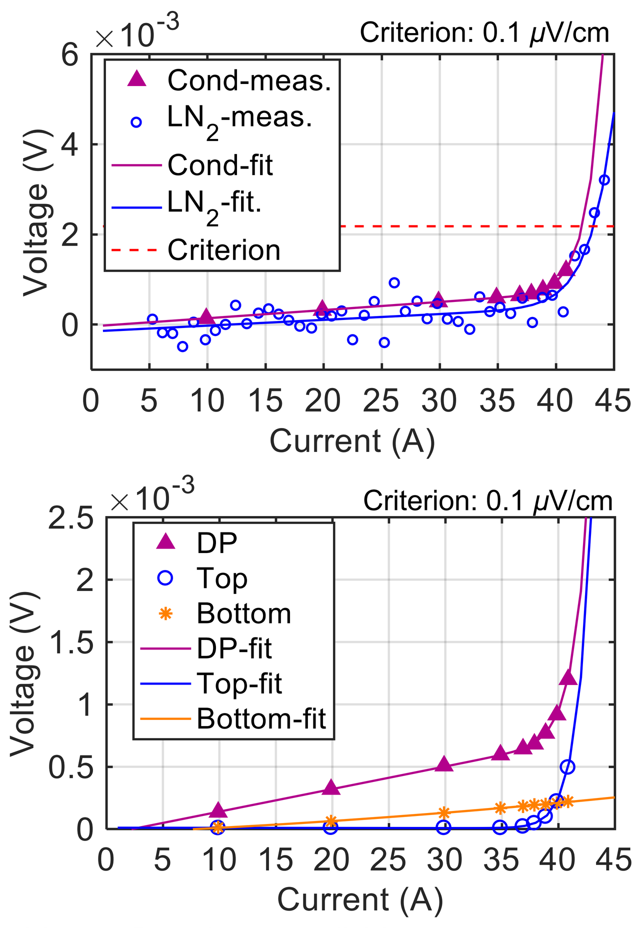
Note: The lift factor is defined as the ratio of the critical current at a specific field to the critical current at 77 K with self field

Coil specification



Tape	GdBaCuO
Tape thickness/width	0.22/4 mm
Min. tape I_c (77 K,s.f.)	100 A
Number of turns	244
Inner/outer radius of the coil	45/83 mm
Height of the coil	19 mm
Height of copper plate	2 mm
Total length of the tapes	218 m

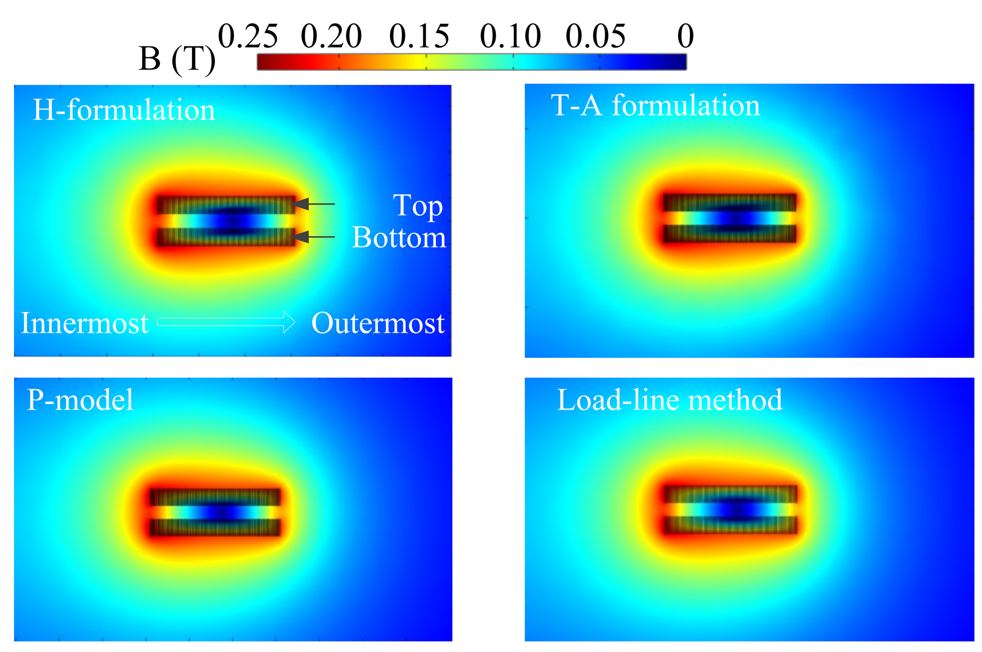
Critical current of the SC coil



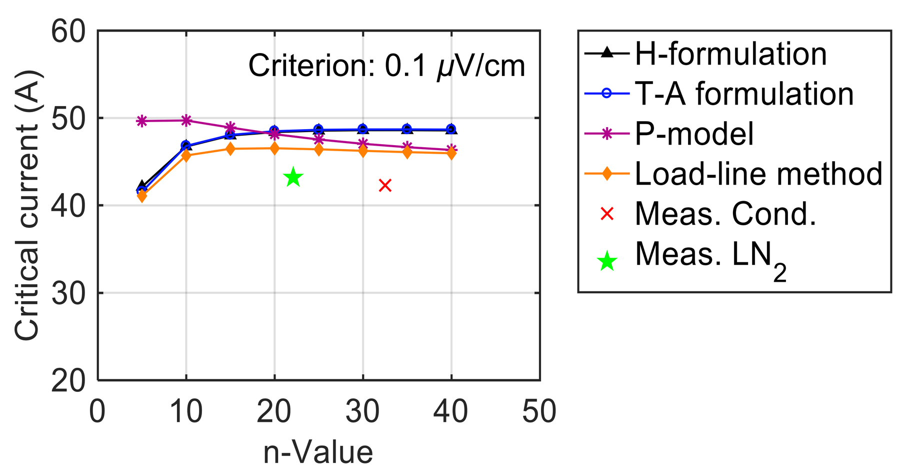
- Critical current
  43.2 A by LN_2
  42.3 A by cond.
- n-value
  22.1 by LN_2
  32.5 by cond.
- Top coil reaches determines the critical current

Note: Cond-meas./LN_2 represents conduction cooling and liquid nitrogen at 77 K (0.1 μV/cm criterion as an example)

Discussion



Magnetic field distribution at operation current of 51 A and n-value of 30 (below critical current with criterion 1 μV/cm)



Criterion	*H*	*T-A*	*P*	Load-line
0.1 μV/cm	14.9%	15.1%	15.6%	10.0%
1 μV/cm	18.1%	18.4%	15.8%	11.4%

Max. deviation of estimated I_c compared to Cond-meas.

Possible reasons to the deviation

- Simulations use a fixed *n*-value, while in reality n-value changes with the magnetic field
- Uniformity of the tape I_c along length (± 20%)
- Length uniformity of the angular dependence of the superconductor (0.3%-6.7%)
- Manufacturing process of the superconducting coil

Due to above mentioned reasons, the coil has a lower Ic than expected based on the short sample measurement.

Conclusion

H-formulation	*T-A* formulation	*P*-model	Load-line method
Applied to all types of SC wires/tapes	Applied to coated superconductors	Applied to all types of SC wires/tapes	Applied to all types of SC wires/tapes
Computation slow	Computation fast	Computation fast	Computation fast

The load-line method gives better result to experiment, not because it explains what happens in the superconductor, but because uniform current density assumption gives lower I_c estimation. If ideal tapes are used, the other three models could give better results

References

[1] Roberto Brambilla *et al* 2007 *Supercond. Sci. Technol.* **20** 16
[2] Z. Hong *et al* 2006 *Supercond. Sci. Technol.* **19** 1246
[3] Fei Liang *et al* 2017 *Journal of Applied Physics* **122**, 043903
[4] V. Zermeño *et al* 2015 *Supercond. Sci. Technol.* **28** 085004
[5] M. N. Wilson 1987 Superconducting Magnets (Monographs on Cryogenics) (Oxford: Oxford University Press) p 352

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