[Thu-Af-Po.05-01] Quench simulations of a 3×3 field shaping NI HTS coil array for a planar coil stellarator

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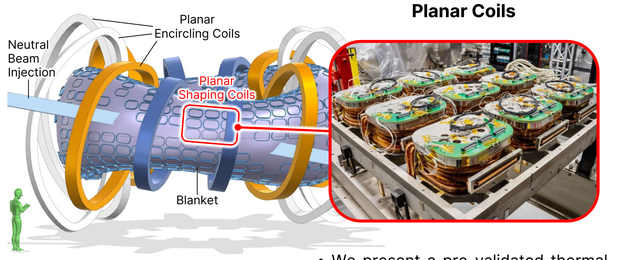
THEA ENERGY

Introduction

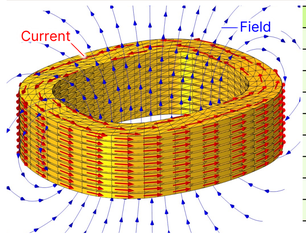
The Eos Planar Coil Stellarator[1]



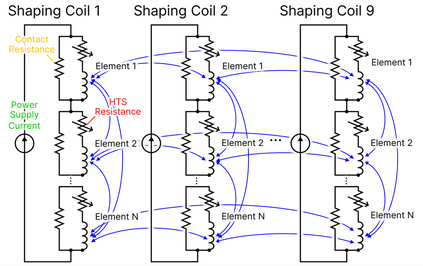
The "Canis" 3x3 Array of HTS Planar Coils

- Thea Energy, Inc. is developing the planar coil stellarator, employing arrays of planar coils to generate the necessary 3D magnetic field for continuous fusion energy.
- "Canis" is a 3x3 planar coil field shaping array technology demonstration[2].
- We present a pre-validated thermal and electro-magnetic quench simulations of the coil array, with a focus on NI coil technology, concerning quench tolerance and resistance.
- We investigate the array's quench stability under realistic and hypothetical conditions.

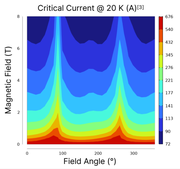
Model Formulation



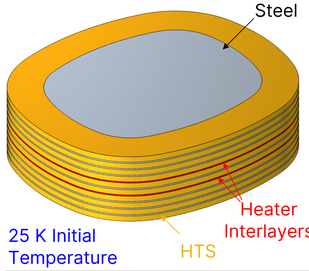
Specification	Value
Coil Shape	Rounded Rectangle
Dimensions	190x163x47 mm
REBCO Tape Width	4 mm
Operating Current	150 A
Turns per Coil	150
Coils per Shaping Coil	10
Stored Energy	4.1 kJ
Coil Architecture	Soldered Metal Insulated
Turn-to-Turn Resistivity	4.4 μΩ·cm²

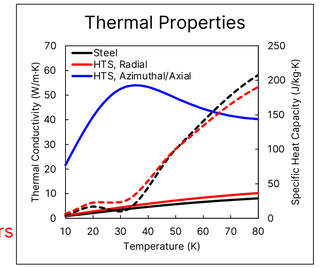


$$\underbrace{\frac{dA_{\phi,i,j}}{dt}}_{\text{Induced Voltage}} + \underbrace{I_{\phi,i,j} \cdot R_{\phi,i,j}}_{\text{Azimuthal Voltage}} = \underbrace{\left(I_{supply,j} - I_{\phi,i,j}\right) \cdot R_{cont,i,j}}_{\text{Radial Voltage}}$$

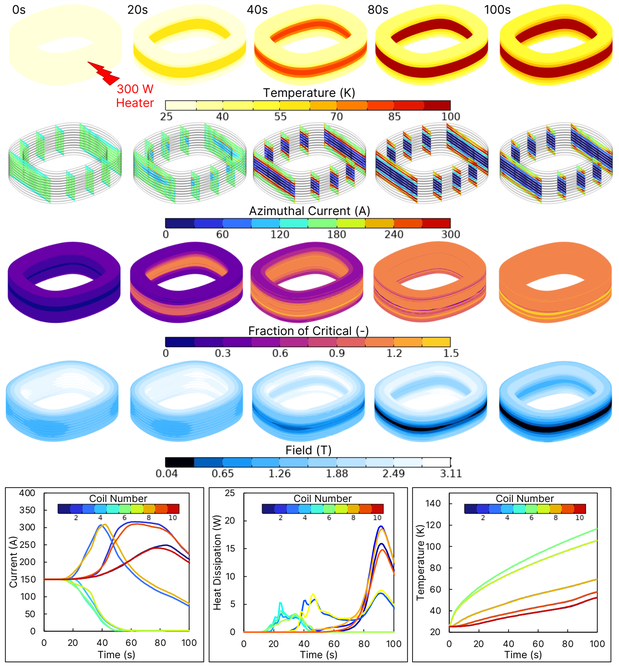


Model Formulation Continued

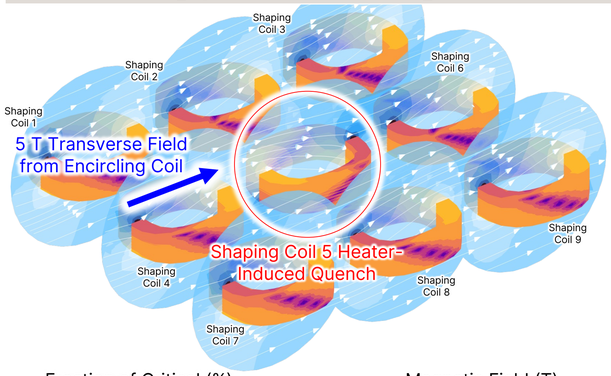


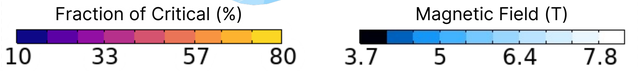


Results 1: Single Shaping Coil Quench

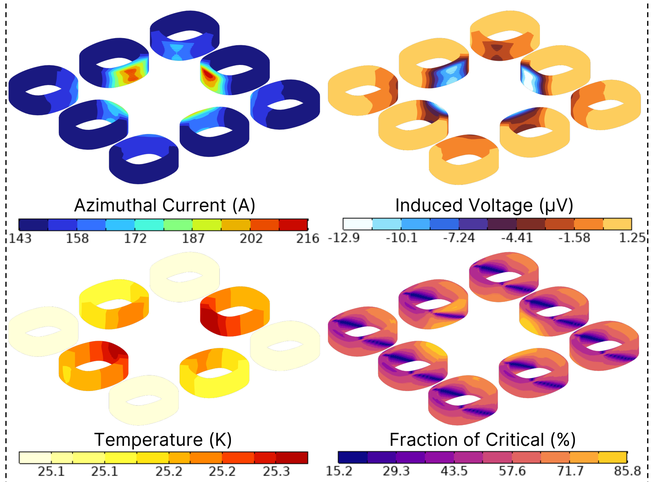


Results 2: Array Quench Under Background Field

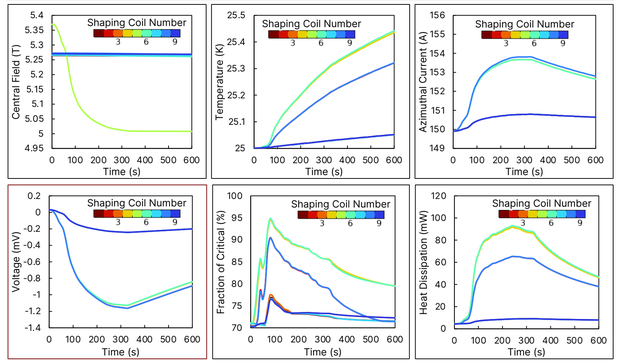




Array Level Impact after 300s of Shaping Coil 5 Heating:



Results 2: Continued



Conclusion

- Planar coil arrays can significantly simplify stellarator design.
- A thermo-electromagnetic finite element simulation of a planar HTS NI coil array was developed.
- Quench simulations suggest a current wave is induced into adjacent coils, but metal insulation enables significant current bypass, preventing hot-spot formation.
- Under a hypothetical 5 T transverse field from an encircling coil, quench of one shaping coil induces current and heating in adjacent shaping coils, but overall coupling is small and NI coil technology slows field decay. This prevents a quench cascade.
- This pre-validated model supports the feasibility of planar coil arrays for stellarators.
- The model will be validated via parameter tuning with experimental data from the Canis experimental campaign to better inform magnet array development.

References

1. Swanson, C.P.S., Gates, D.A., Kumar, S.T.A., Martin, M.F., Kruger, T.G., Dudt, D.W., & Bonofiglo, P.J. (2025). The scoping, design, and plasma physics optimization of the Eos neutron source stellarator. Nuclear Fusion, 65(2), 026053.
2.Nash, D., Gates, D.A. et al. (2025). Prototyping and Test of the "Canis" HTS Planar Coil Array for Stellarator Field Shaping. https://arxiv.org/abs/2503.18960
3.Wimbush, S., Strickland, N., and Pantoja, A. (2021). Critical current characterization of SuperOx YBCO 2G HTS superconducting wire. Figshare, Dataset, 2021, doi: 10.6084/m9.figshare.13708690.v1.

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