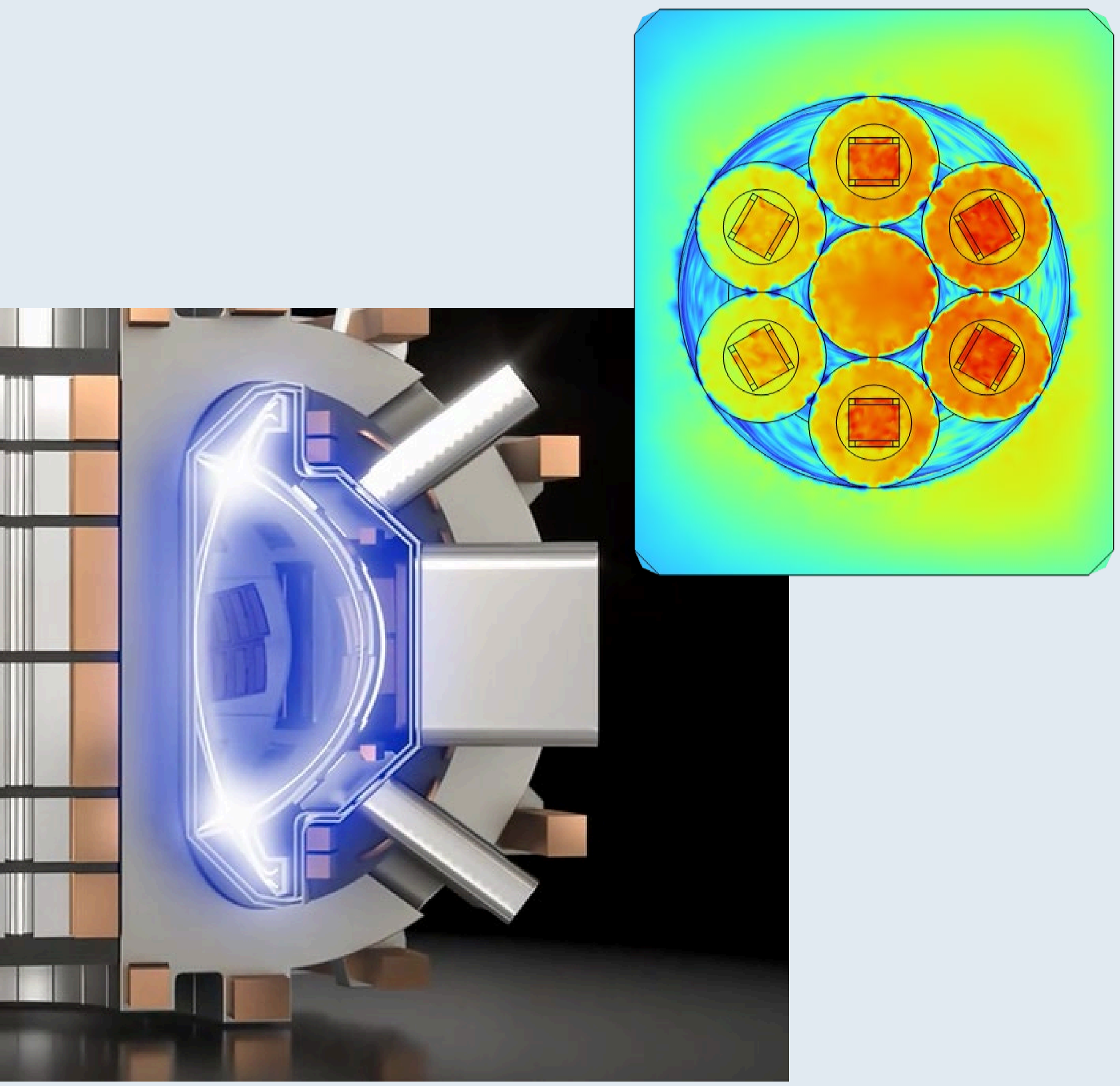


Multiphysics Framework for Nuclear Heating Effects on HTS-Based Cables

Exploring the mechanics behind the potential performance degradation of high-field high-current cables during normal fusion devices operation.

S. Sparacio[1,2], M. Fracasso[1,2], F. Ledda[1,2], D. Torsello[1,2], L. Gozzelino[1,2], G. Ghigo[1,2], R. Gerbaldo[1,2], and F. Laviano[1,2]

1 Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy
2 Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Torino, Italy

Abstract

HTS-based cables, such as the Cross Conductor (CroCo) layout proposed by KIT [1], are promising candidate for winding the Toroidal Field (TF) coils of compact nuclear fusion machines [2]. Their helical arrangement allows for efficient current distribution, reducing current imbalance and enhancing the overall current-carrying capability and current sharing of the cable system.

However, an in-depth analysis of the thermo-magnetic response of the cable, under high transport current and operating temperature, and considering the effects induced by the D-T plasma operation [3], is of paramount importance for unlocking their full potential for practical applications.

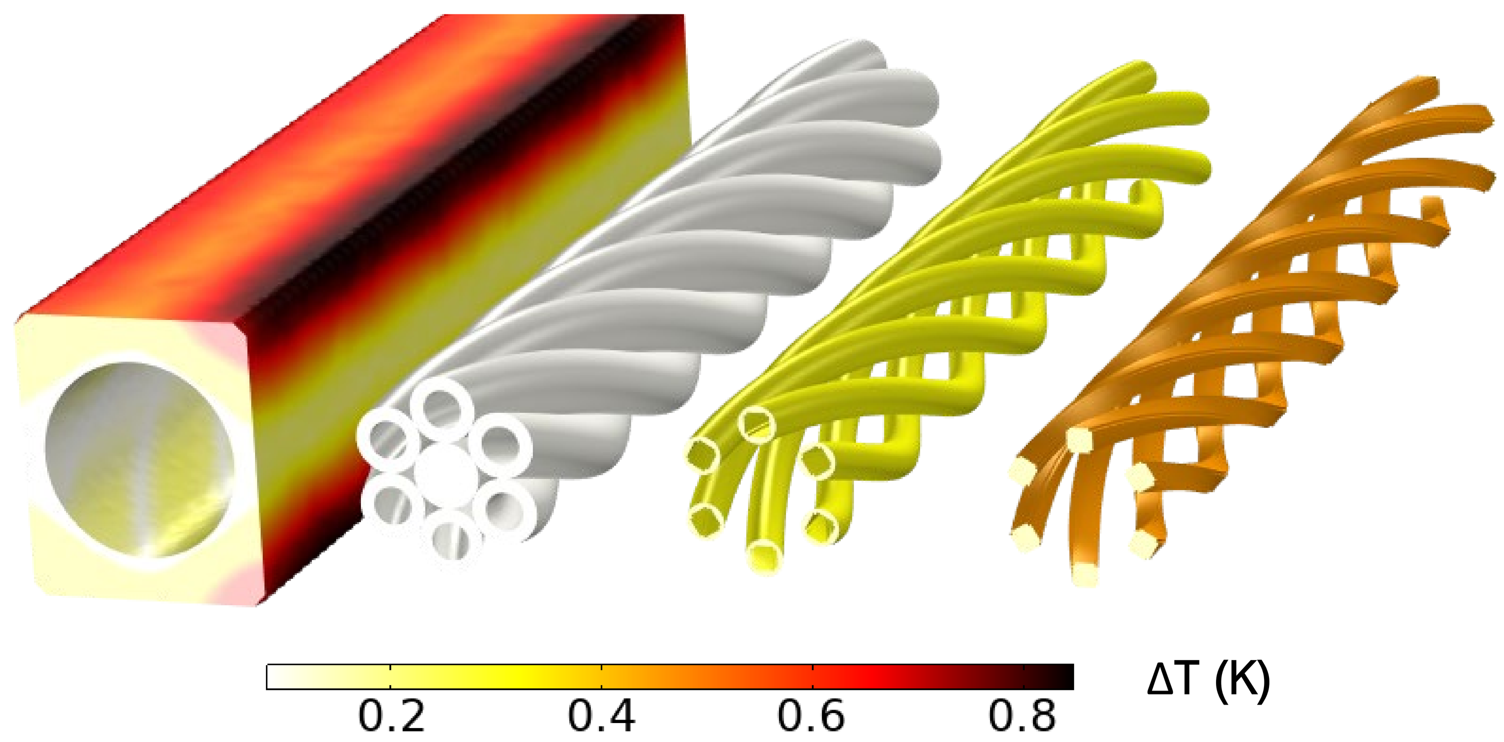
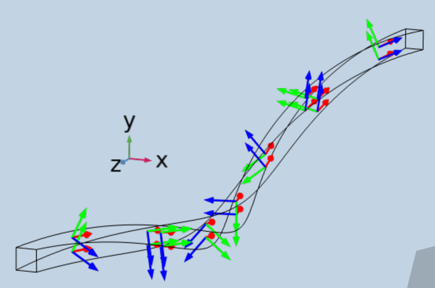


FIGURE 1. Temperature increment of each cable's component (i.e., external jacket, copper matrix, solder, HTS bulks) with respect the expected operating temperature (T_{op}=20 K), on a logarithmic scale for highlighting internal gradients.

Modeling Framework

Curvilinear Coordinates (cc module):

To account for:
- the helical pattern of the geometry;
- the anisotropic structure of REBCO tapes.



Thermal Analysis (ht module):

Fourier equation:

$$\nabla \cdot (-k_i(\theta)\nabla\theta) + Q = 0$$

$Q\ (W/m^3)$ is the long-term, stationary, irradiation-induced (including both neutrons and secondary particles) volumetric heat deposition

EM Analysis (mf + PDE module):

Ampere's law:

$$\nabla \times \left(\frac{1}{\mu}\nabla \times \boldsymbol{A}\right) = \boldsymbol{J}$$

Faraday's law:

$$\nabla \times (\rho \nabla \times \boldsymbol{T}) = -\frac{\partial \boldsymbol{B}}{\partial t}$$

E-J constitutive law:

$$\frac{\boldsymbol{E}}{E_c} = \left(\frac{\boldsymbol{J}}{J_c(\boldsymbol{B},T)}\right)^n$$

Results and Conclusion

✓Quite homogeneous temperature within each cable's component and small temperature increment;

✓Thermal contact resistances change the temperature gradients, with a maximum temperature in the middle of the stacks;

✓No evident degradation of the electromagnetic performances, along the considered pitch, due to the temperature increment;

✓Small difference in the current density profile induced by the temperature gradients.

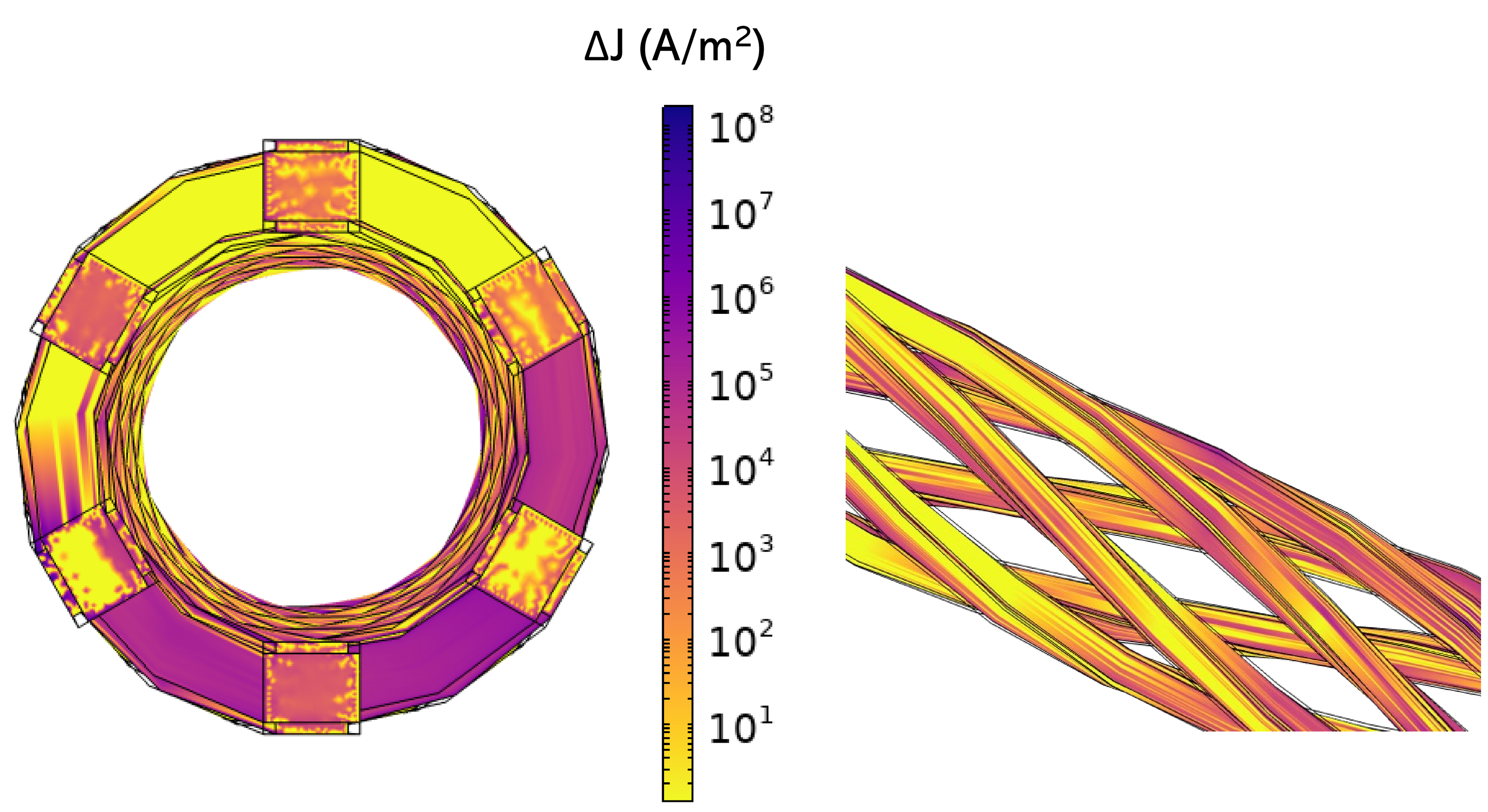


FIGURE 2. Relative difference between the current density profile evaluated at the temperature obtained from the thermal analysis and the one at 20 K, on logarithmic scale. (left) 2D cross-section, right) 3D cable. The expected current for the present layout @ 20 K, self-field is ~45 kA.

REFERENCES

[1] M. J. Wolf, et al., "HTS CroCo: A Stacked HTS Conductor Optimized for High Currents and Long-Length Production," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 2, pp. 19–24, Mar. 2016, doi: 10.1109/TASC.2016.2521323.
[2] B. N. Sorbom *et al.*, "ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets," *Fusion Eng. Des.*, vol. 100, pp. 378–405, Nov. 2015, doi: 10.1016/j.fusengdes.2015.07.008.
[3] F. Ledda et al., "3D neutronic and secondary particles analysis on YBCO tapes for compact fusion reactors ," *IEEE Trans. Appl. Supercond.*, vol 34, no. 3, pp. –, May 2024, (submitted)

**This work is partially supported by ENI S.p.a..

Politecnico di Torino

eni

INFN Istituto Nazionale di Fisica Nucleare