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## Editorial

# Focus on numerical modeling of high temperature superconductors—HTS 2024

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Recent applications of high temperature superconductors (HTSs) demand the development of advanced numerical models to alleviate computational burdens, with a particular emphasis on multiphysics approaches. This series introduces the latest trends in HTS modeling, compiling several works presented at the 9th International Workshop on Numerical Modeling of HTSs (HTS 2024).

The workshop was organized by the Magnet Section of the Paul Scherrer Institute (PSI) and held at the Parkhotel Bad Zurzach, Switzerland, from June 10–13, 2024. Three main aspects were addressed:

- innovative methods and tools for modeling large-scale HTS systems
- coupled and uncoupled multiphysics problems
- applications in large-scale instruments such as high-field magnets, medical magnets, and accelerator magnets.

## (1) Innovative methods and tools for modeling large-scale HTS systems

A new approach based on the frequency-domain simulation of HTS was introduced [1]. This model demonstrated comparable or even superior accuracy to the classic time-domain approach, with significantly reduced computational time. However, its applicability is currently limited to steady-state alternating current conditions owing to its formulation in the frequency domain. An extension of mixed finite-element electromagnetic formulations ( $\mathbf{J}-\mathbf{A}-\Phi$  and  $\mathbf{T}-\mathbf{A}-\Phi$ ) was also presented [2]. These formulations reduce the computational load by incorporating the magnetic scalar potential ( $\Phi$ ), which decreases the degrees of freedom and thus accelerates calculations while saving memory. A crucial step in these methods is the addition of a thin cut in the mesh to enforce Maxwell–Ampere’s law. The construction of this cut, typically complex and requiring Homology/Cohomology considerations, is simplified using an intermediate  $\mathbf{A}$  formulation, easing geometry handling and avoiding ancillary mathematical problems.

## (2) Coupled & uncoupled multiphysics problems

This topic focuses on electromagnetic–thermal coupling and benchmarking of different codes and software [3]. The main objective was to develop computationally efficient homogenized models to simulate quenches in HTS devices, such as pancake or racetrack coils. Finite element models using different Maxwell formulations were compared with the minimum electro-magnetic

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entropy production in-house code, both incorporating heat transfer. The homogenized models showed excellent agreement with fully detailed geometrical models of HTS tapes. Additionally, a 3D multiphysics model incorporating electrical, thermal, and computational fluid dynamics effects was presented. It used the finite volume method in Simcenter STAR-CCM+ (Siemens Digital Industries Software) [4] and was validated against experimental data from the SULTAN test facility. Unlike typical liquid nitrogen applications at 77.3 K, this study investigated operating conditions at 6.7 K and 10.2 bar, achieving fair agreement between simulated and measured voltages and temperatures despite the system's complexity.

### (3) Applications in large instruments such as high-field magnets, medical magnets and accelerator magnets

Several studies focused on applying HTS modeling to high-field magnet development, next-generation accelerators, and advanced power cables.

These works align with the broader objectives of the HTS Modeling Working Group:

- Providing shared numerical benchmarks to compare and validate models across institutions.
- Developing predictive multiphysics tools for high-field and large-scale applications.
- Fostering collaboration between research centers, universities, and industrial partners to accelerate technology transfer.
- Addressing design challenges for future HTS-based systems, including radiation, quench behavior, and thermal management.

### Data availability statement

No new data were created or analysed in this study.

### Author contributions

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Conceptualization (lead), Project administration (lead), Writing – review & editing (equal)

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Conceptualization (supporting), Writing – review & editing (equal)

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