Opera-3d Superconducting quench module

The most important thing we build is trust

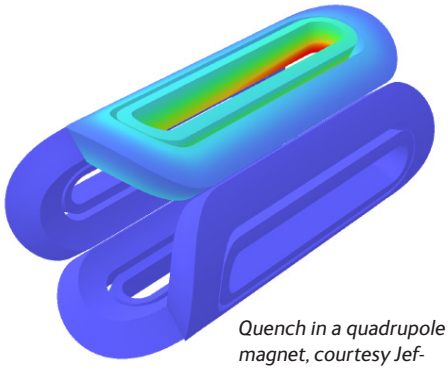
Opera Simulation Software
COBHAM

Users of Opera-3d's integrated suite of finite element (FE) software for electromagnetic device simulation can analyse quenching of superconducting magnets. The Opera-3d quench module computes the temperature rise of a superconducting magnet during a quench, including the transition to being resistive as the quench propagates through the magnet.

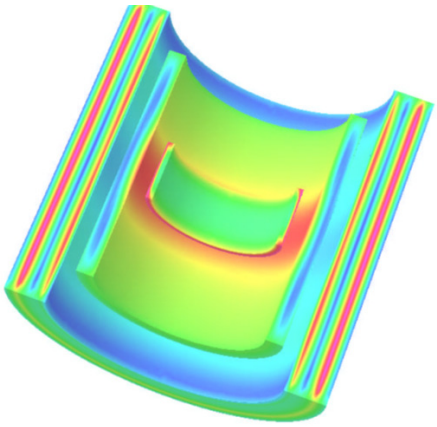
The quench module uses advanced FE techniques to model the highly non-linear transient behaviour of a magnet during a quench. Using an algorithm which couples the electromagnetic solution to the thermal and circuit solutions (to determine the currents in the coils), users can analyse the full quenching process.

The quench process

One of the initiating mechanisms for a quench is believed to be local heating inside the superconducting coil as a result of micro-movements. Opera-3d users can simulate this mechanism using a local heat source at a user-defined point inside the coil. Users can also model quenching triggered by rate-dependent losses as



Quench in a quadrupole magnet, courtesy Jefferson Laboratory



Quench in a LTS magnet which has an HTS

magnetic fields change (for example due to quench in an adjacent coil). Opera-3d simulates the propagation of a quench from its trigger point and users can investigate the susceptibility of a magnet or system of magnets to quenching, and the effectiveness of devices used to protect magnets in the event of a quench.

Full System Modelling

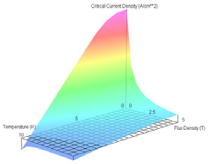
Using an FE model, Opera-3d simulates the local temperature rise that occurs, and propagates, during a superconducting magnet quench. The superconductor's critical current density is defined as a function of the local temperature and magnetic flux density. This is used to determine material properties as the superconductor transitions from the superconducting to the resistive state.

Opera-3d couples electromagnetic and thermal analyses to a circuit representation of the coil to calculate currents in the windings. When additional entities, such as a conducting former or shielding are required, the quench module will also couple to Opera-3d's transient electromagnetic solver for a full solution. By coupling the analyses, users can model the non-linear behaviour during the quench process and investigate in detail. With these results, users can investigate the effectiveness of the protection circuits and other devices (e.g. quench bands). They can also investigate the sensitivity of the magnet to a quench including secondary quenching of adjacent magnets by rate dependent losses.

Functional Materials

Modelling material properties as a function of the local field and temperature is essential to effectively simulate the quench process. This is because the process is highly non-linear (some material properties varying by orders of magnitude during a quench). In Opera-3d users can define the critical current density of the superconducting material as a function of temperature and magnetic field using functional tables. This allows users full control over the material properties.

Opera-3d can simulate magnets that comprise complex superconducting cables with high levels of anisotropy and non-linear behaviour. Users can model noth low-temperature (LT) and high-temperature (HT) superconductors. The quench module is supplied with material properties for Sumitomo HTS materials.



Critical current density as a function of flux density and temperature

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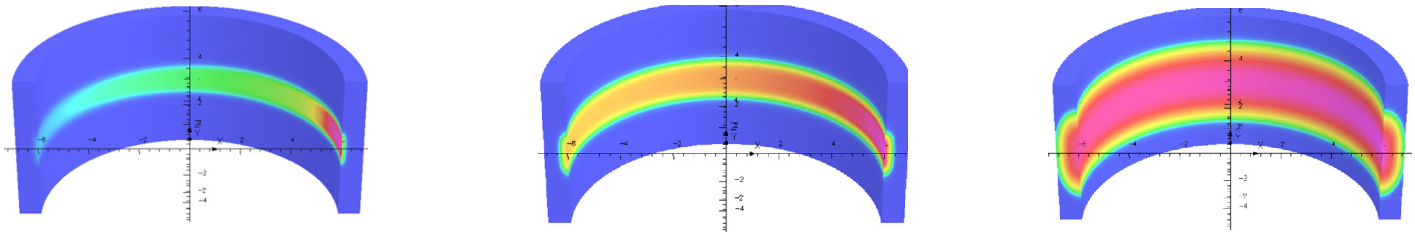
Applications

- Magnet quenching
- Induced quenching
- Quench-band analysis
- Protection circuit design
- Low temperature superconductors
- High temperature superconductors
- Inter-turn/layer voltages

A combination of Opera solvers are used for different types of Quench problems:

	Modeller/post processor	Quench module	Thermal analysis	Transient electromagnetics
Quench analysis (coils only)	✓	✓	✓	
Quench with eddy currents and permeable materials in surrounding structure	✓	✓	✓	✓



100 ms 200 ms 500 ms

Propagation of a quench in a LT superconducting magnet

Customer Support

We provide support to Opera users from our offices in the UK and the USA, and through a worldwide network of local distributors. Our support engineers have an extensive knowledge of superconducting magnet design and are available to assist both existing and prospective customers with their design requirements.

For more information about Opera and the numerical simulation of superconducting magnets and the quench process, please refer to our website, operaFEA.com, which is dedicated to the finite element modelling of all types of magnets. This website contains information, including a range of technical publications, videos and webinars, of general interest to engineers involved in magnet design.

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