Quench & protection: modelling and review of toolings

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with the great help of:

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Introduction

This presentation mostly comes from the description done by Helene Felice in WAMSDO-2013.

It's a review of some codes. For each code it will described:

- **Code "ID"**
  - Overview
  - Programming
  - Validation
  - Distribution / Availability
  - Some users
  - Some references

- **Brief description**

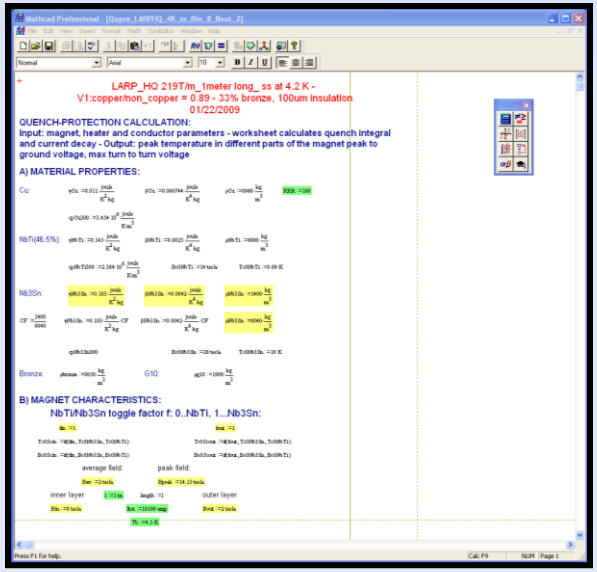
Non exhaustive list of codes

We can distinguish 2 kinds of codes:

- **<u>Highly specialized "quench protection" codes</u>**
  - QuenchPro (FNAL)
  - QLASA (INFN-LASA)
  - ROXIE (CERN)
  - Cobham Vector Field Quench Analysis program (VF)

- **<u>More general codes applied to quench protection:</u>**
  - FEM codes: ANSYS, CAST3M

QuenchPro ID



QuenchPro developed at FNAL by P. Bauer

Overview

Adiabatic model

Calculation of the hot spot temperature and current decay

Programming

Mathcad 7 spreadsheet developed by Pierre Bauer

Validation

LARP magnets and comparison with other codes (QLASA)

Availability

Available upon request to the owner (Pierre Bauer or Giorgio Ambrosio)

Some users

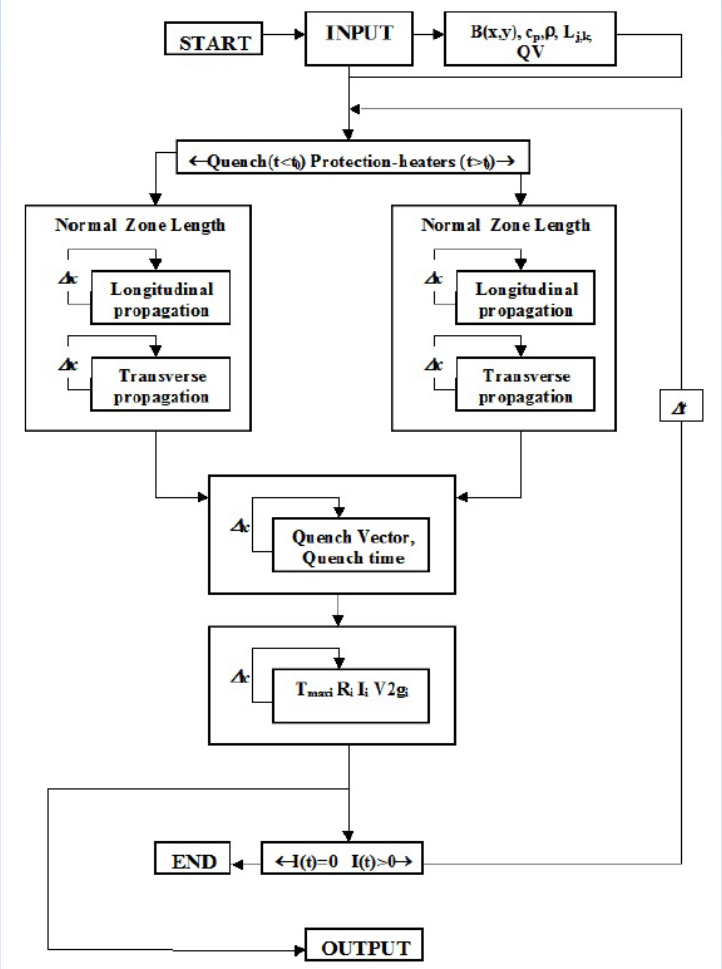
Giorgio Ambrosio (FNAL), Helene Felice (LBL)

Some References

P. Bauer et al., FNAL TD-00-027, FNAL TD note TD-01-003 and 4

Lidia Rossi, FNAL TD-12-11

QuenchPro - Principle



Flowchart from Lidia Rossi thesis – TD-12-11

Part 1:

- **Input**
  - Definition of the magnet in a series of 16 sub-coils
  - Magnet Operational Parameters: field, bath temperature
  - Preliminary calculations of the material properties
  - Definition of the protection system
    - Value of the dump
    - PH: coverage, delay…
    - Detection time
- **Normal zone propagation Routine** – for each time step
  - Calculation of the resistance
  - Current decay: exponential, with τ_i update each temporal step t_i
  - Temperature: computed based on the MIITs accumulation at t_i

QuenchPro – Principle(II)

Part 2:

- **Voltage computation**

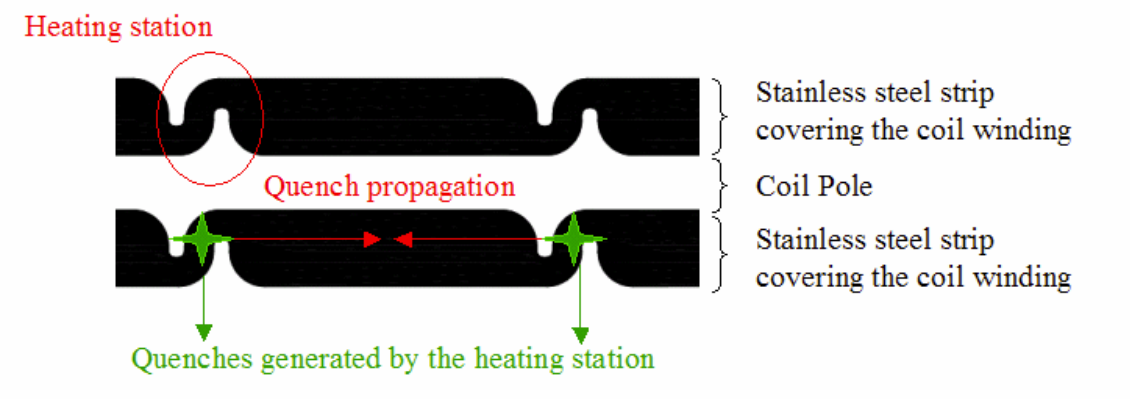
- Definition of each turn coordinates to allow the calculation of the turn to turn inductance => inductance matrix
- Calculation of the turn to turn voltage and turn to ground voltage

Some Limitations

- Absence of user manual
- Various versions modified by various people
- No quench-back effect

QuenchPro improvement by Lidia Rossi (available upon request to G. Ambrosio)

Implementation of heating stations



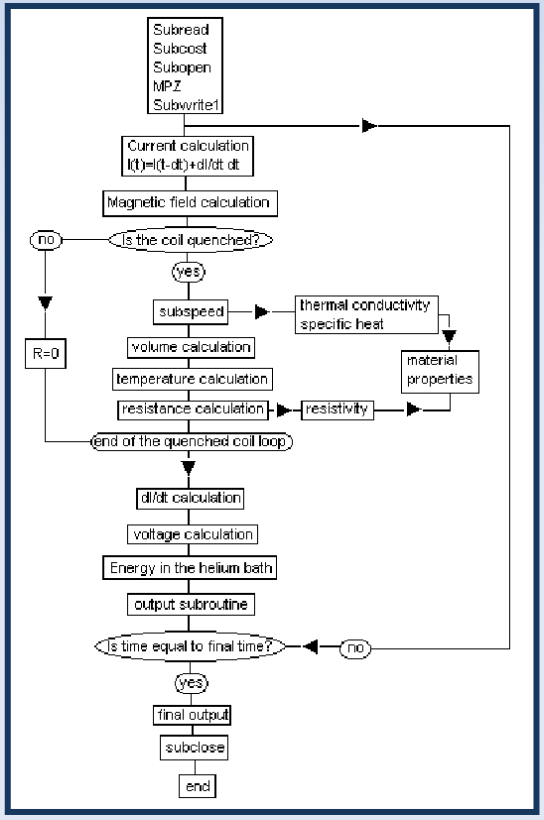
Example of LARP Long Quad (LQ)

- Normal zone growth account for quench propagation from heating stations

Implementation of the differential inductance

- Initially constant in the original QuenchPro
- “If” loop to introduce L(I)

QLASA - ID



Overview

Quench code developed at **LASA**

Adiabatic assumption for hot spot temperature calculation

Initially intended for superconducting solenoids and inductively coupled elements

No quench-back effects

Programming

Fortran 77

Availability

Available upon request to the owner (INFN-LASA)

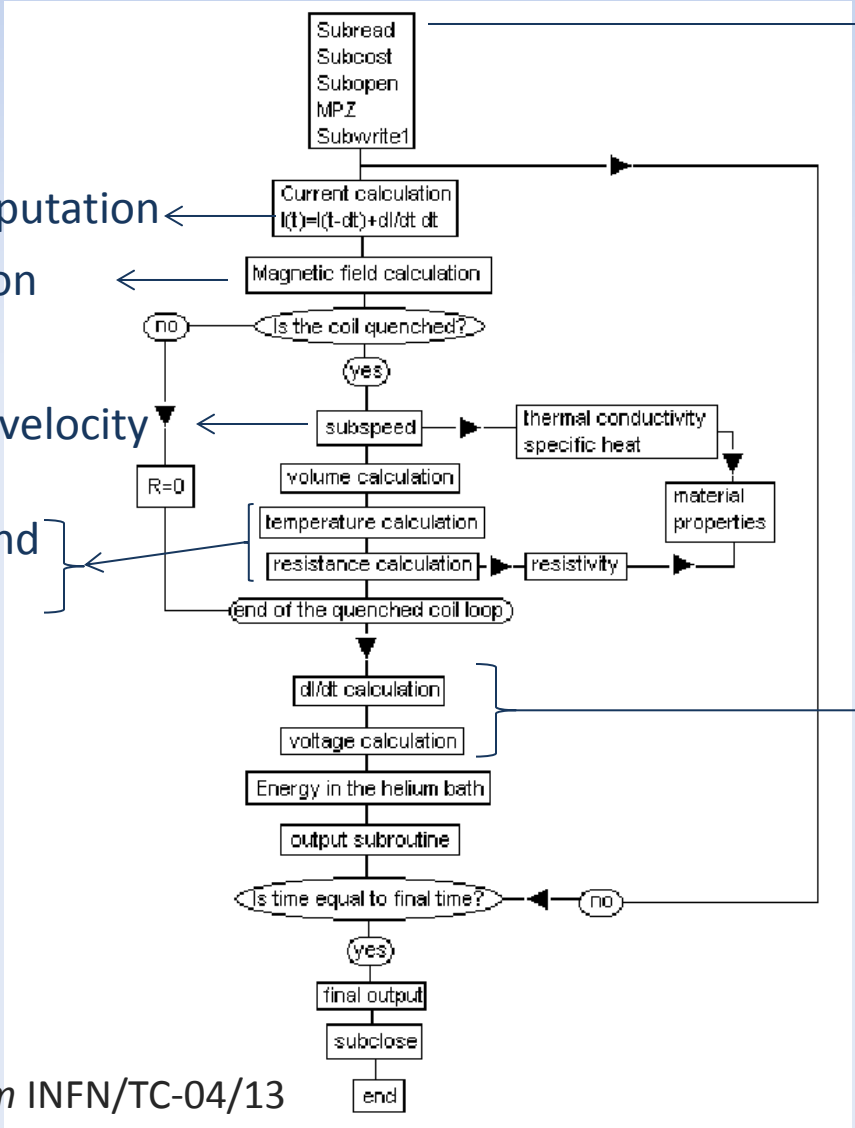
Some users

Massimo Sorbi, Vittorio Marinozzi (INFN – LASA)

Some References

L. Rossi, M. Sorbi, *QLASA: a computer code for quench si,ulation in adiabatic multicoil supercond. winding* INFN/TC-04/13

QLASA - Principle



Current computation

B computation

Propagation velocity computation

Resistance and Temperature

Flowchart from INFN/TC-04/13

Reads the input data

- Geometry
- Time steps
- Vtaps location
- Self an Mutual inductance
- Cable components
- …

Current decay

Voltage:

- Driven Mode: Accounting for change of mode of the power supply (from current mode to voltage mode)
- Persistent mode available

Material properties library: MATPRO

- *Fortran 77* computer library providing electrical and thermal properties of most common materials used for the construction of superconducting magnets. The physical properties dealt by the code are:
    1. Density.
    2. Specific heat.
    3. Electrical resistivity
    4. Thermal conductivity.

- It covers typical material for LTC Supercond. (NbTi, Nb3Sn, Copper, G10, Bronze, Al, Stainless-steel, Kapton,….) but also some material for HTC (YBCO, BSCCO, Ag) - less tested..
- Matpro can be included as an external routine by others codes (QLASA, Roxie, etc.)

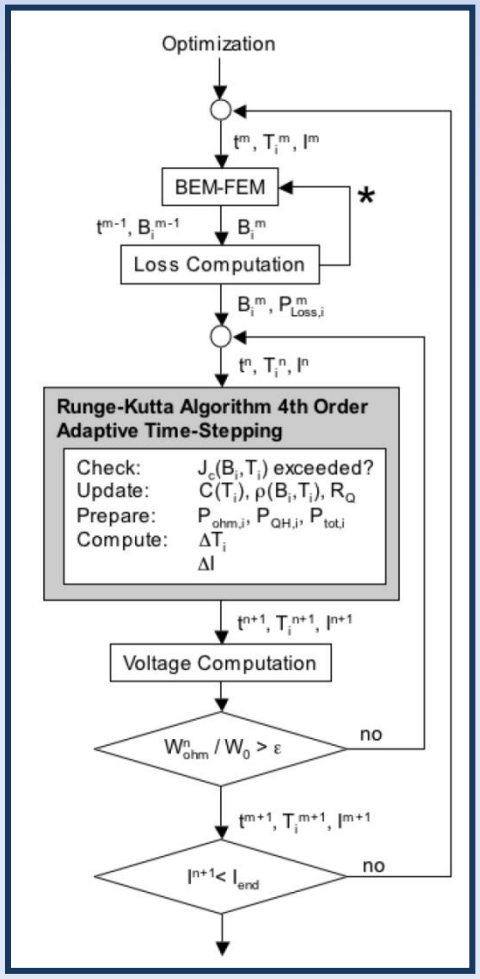
Availability

Available upon request to the owner (INFN-LASA)

Ref.

G. Manfreda, L. Rossi and M. Sorbi, *" MATPRO -Upgraded version 2012: a Computer Library Of Material Property At Cryogenic Temperature",* INFN-12-04/MI

ROXIE Quench Module ID



Overview

Solve the heat equation by FEM

Programming

Developed by Nikolai Schwerg and Bernhard Auchmann

Validation

TQ , 11 T dipole

Availability From CERN with the ROXIE license

Some users

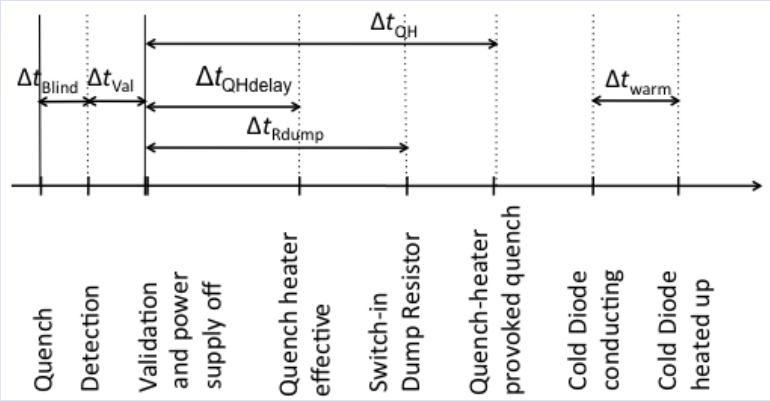
Bernhard Auchmann, Susanna Izquierdo Bermudez (CERN)
Tiina Salmi (LBNL)

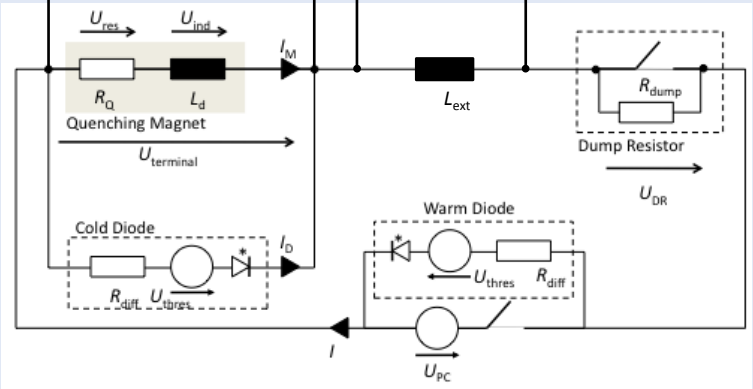
Some References

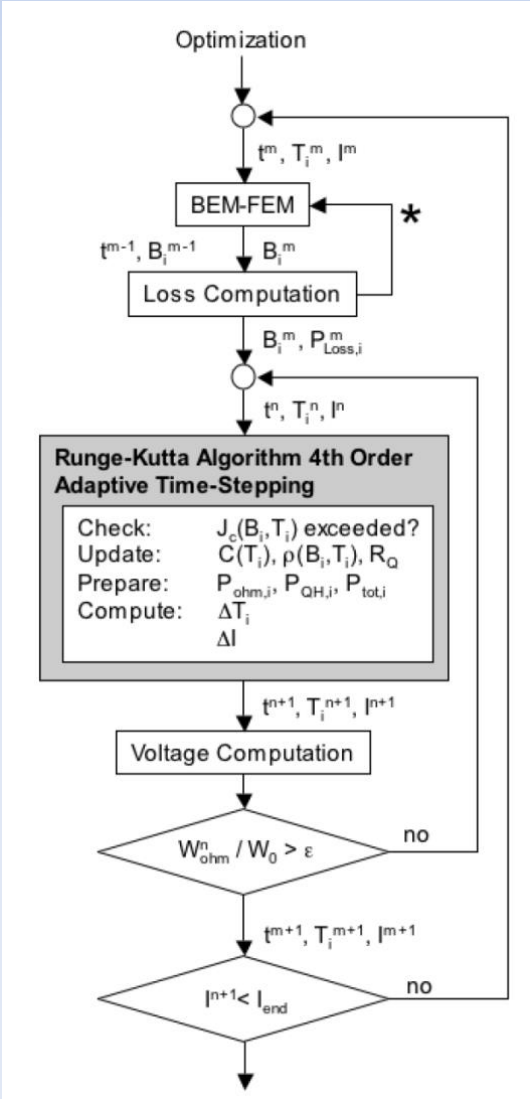
N. Schwerg et al.,, IEEE Trans. On Magn., Vol. 44, N. 6, June 2008
N. Schwerg et al., IEEE Trans. On Appl. Supercond, Vol. 19, No. 3, June 2009

ROXIE - Description

N. Schwerg et al., “Quench simulation in an integrated design environment for superconducting magnets”.
IEEE Trans. on Magn., vol 44, June 2008.







ROXIE Description (II)

The heat equation is discretized by an equivalent thermal network model.

$$C\frac{\mathrm{d}T}{\mathrm{d}t} = P_{\mathrm{Joule}} + P_{\mathrm{beam}} + P_{QH} - \mathrm{div}\,\lambda\,\mathrm{grad}\,T$$

In the coil cross-section, each conductor corresponds to a node in the network

The thermal model considers:

- cooling to a cold surface,
- the influence of helium
- heat sources due to ohmic heating,
- quench heaters: no diffusion time computation
- induced losses (which is a form of quench-back)

- It is a 2D modeling, with the 3rd dimension longitudinal subdivision supplied by the user (not the details of coil-ends).

ROXIE Material properties

G. Manfreda, Review of ROXIE's material properties database for quench simulation, EDMS 1178007, Nov 2011

MATPRO:

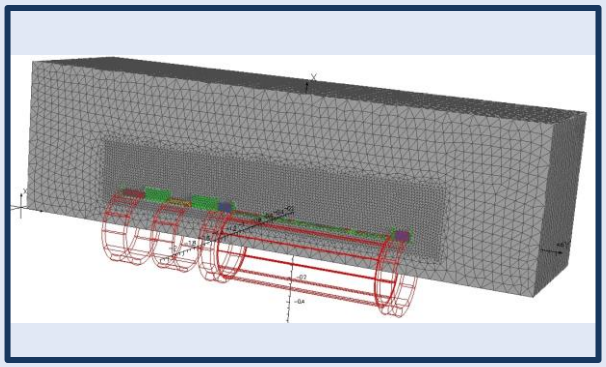
- collection of cryogenic material properties from Università degli Studi di Milano and Istituto Nazionale di Fisica Nucleare (INFN)
- developed with the work, among the others, of Lucio Rossi and Massimo Sorbi.
- database used by QLASA quench simulation code;

NIST: the official website of the National Institute of Standard and Technology contains a database of cryogenic material properties;

CryoComp:

- collection of properties for materials commonly present in superconducting magnets.
- version 5.1. CryoComp material properties are for example used in Qcode from Lawrence Berkeley National Laboratory.

Cobham Vector Field – Quench Analysis Program



Overview

The Quench Analysis Program is one of the Analysis programs of the Opera-3D Analysis Environment.

- Incorporates the non linear solution of the transient problem using the **TEMPO-Transient Thermal Analysis**

- Can be coupled with **ELEKTRA/TR analysis** to model transient electromagnetic fields and external circuits

Validation

Wilson code, MICE spectrometer

Availability

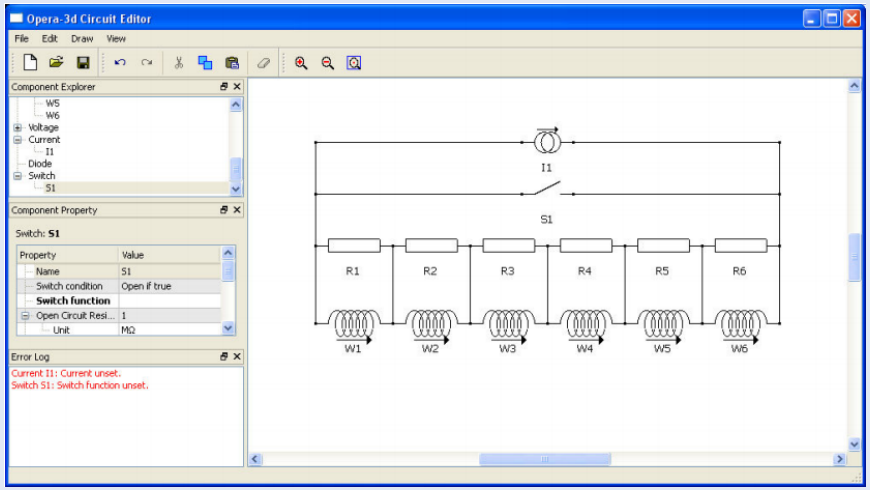
$$ Cobham

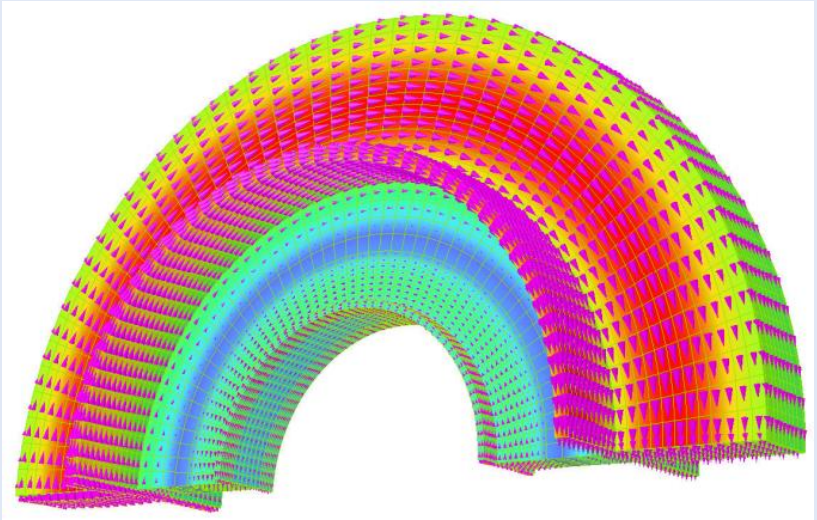
Some users

Heng Pan (LBNL)

Vector Field Quench Analysis Program

- Material properties need to be more referenced
- Material properties used at LBNL: Cryocomp.
- It has the advantages of a “commercial” specialized code: documentation, graphics, easy-accessibility…





FEM - ANSYS

Programming

FEM (thermal analysis)

- Current externally guided (i.e. exponential decay, voltage constant, measurements…)
- Calculates temperature and voltage distribution

Availability

$$ ANSYS

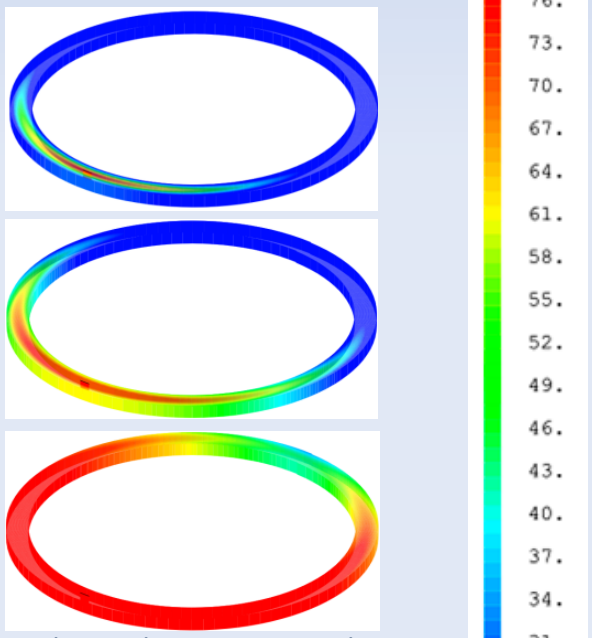
Some users

S. Caspi (LBNL), P. Ferracin (CERN), R. Yamada (FNAL)

Some References

- S. Caspi et al., and published in “Calculating Quench Propagation With ANSYS”, IEEE Trans. Appl. Supercond, Vol. 13, No. 2, June 2003
- P. Ferracin et al., “Thermal, Electrical and Mechanical Response to a Quench in Nb3Sn Superconducting Coils”, ”, IEEE Trans. Appl. Supercond, June 2004
- Yamada et al. present a thermal – mechanical analysis in “2D/3D Quench Simulation Using ANSYS for Epoxy impregnated Nb3Sn High Field Magnets” in IEEE Trans. On Applied Superconductivity, Vol. 13, No. 2, June 2003

FEM CAST3M- ID



Simulation de propagation dans une bobine d'YBCO (champ de température)

Overview

- Finite element code developed and used at CEA
- Compute eddy currents in coil casing → quenchback
- Use FEM thermal analysis for heat diffusion & quench propagation

Programming

FEM

Validation: CMS, RD3b

Availability: Free

Some users: Philippe Fazilleau (CEA)

Some References

-P.Verpeaux, T. Charras, and A. Millard,"CASTEM 2000 une approche moderne du calcul des structures," in *Calcul des structures et intellig. artificielle*, Pluralis, 1988, pp. 261–271.

-P. Fazilleau et al. "The R3B-GLAD Quench Protection System", IEEE Trans. On Applied Superconductivity, Vol.. 20, No. 3, June 2010

In summary

- A NON EXHAUSTIVE list of codes
- Many labs. have their own developed code
- Need to pick the right code fitting the user's goals
  - Adiabatic code → very fast results (for parametric study)
  - FEM code → time consuming (detailed 3D analysis)
- Most of the codes are free and accessible but some might lack of documentation
- Need the validation with experimental data for HTS