Design and Optimization of a HTS Insert Coil for Solenoid Magnets

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ENEA

Outline

- Introduction & Scope
- State of the art ENEA HTS CICC
- Thermo-Magneto-Mechanical Finite Element Model
- Optimization Methodology
- Results
- Conclusions and perspectives

Introduction & Scope

- Recently, a HTS CICC cable comprised of 2nd generation ReBaCuO coated conductors has been **designed and manufactured** by ENEA

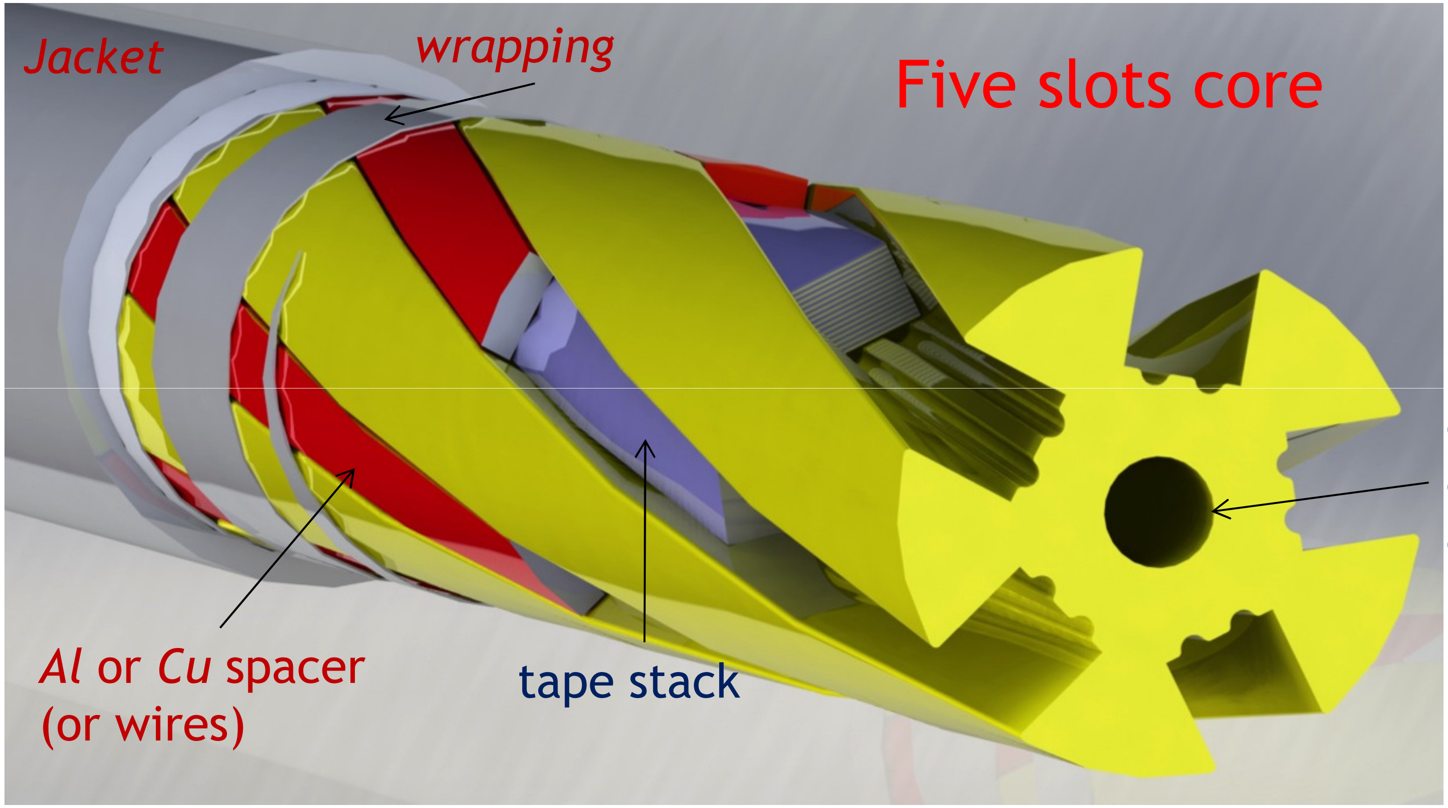
- With the availability of 2G HTS, high field magnets are now being considered

- The ENEA HTS system is considered to be inserted into the bore of an existing high field magnet

- **Scope of this work** is to propose a **methodology** to minimize the needed HTS cable length
  - to achieve a certain **peak field** (let's say **17 T**) starting from a **background field** (for example **12 T**)
  - withstanding the relative Lorentz forces and cool-down thermal stress

The ENEA slotted core CICC

10 kA – class cable: 150 2G-wires (5 stacks x 30 wires)



inspired by the MIT concept for twisted-stacked tape CICC

cooling central channel

Fundamental Design driver: industrial process feasibility

TRATOS CAVI

Problem Description

- Find the best geometry for the high field HTS insert demonstration magnet, with:
  - a background field

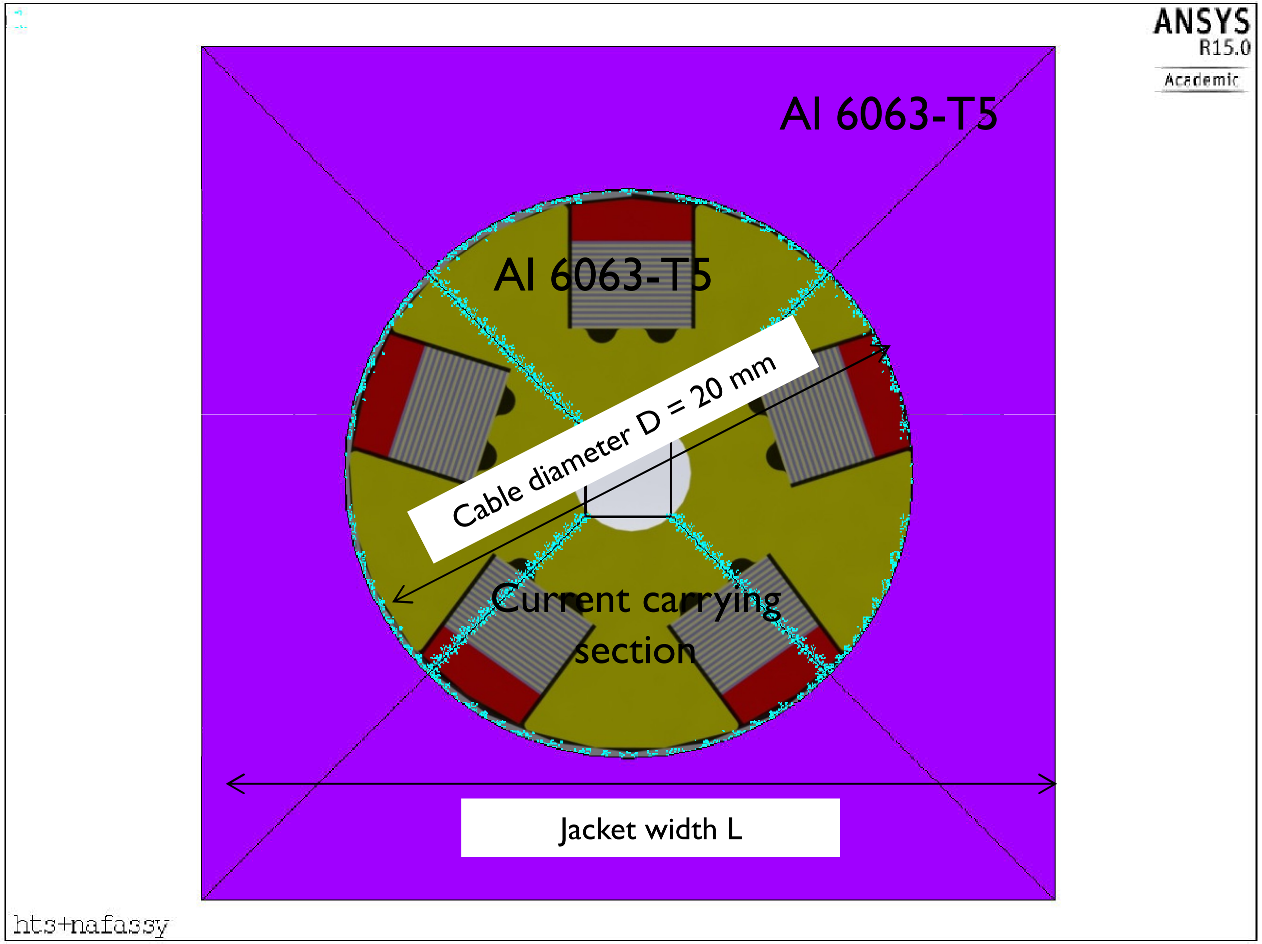
- In order to:
  - Minimize total conductor length
  - Guarantee structural integrity
  - Achieve a certain peak magnetic field

- With a design constraint on:
  - the minimum bore curvature radius (due to the strain tolerance of Jc in superconducting tapes)

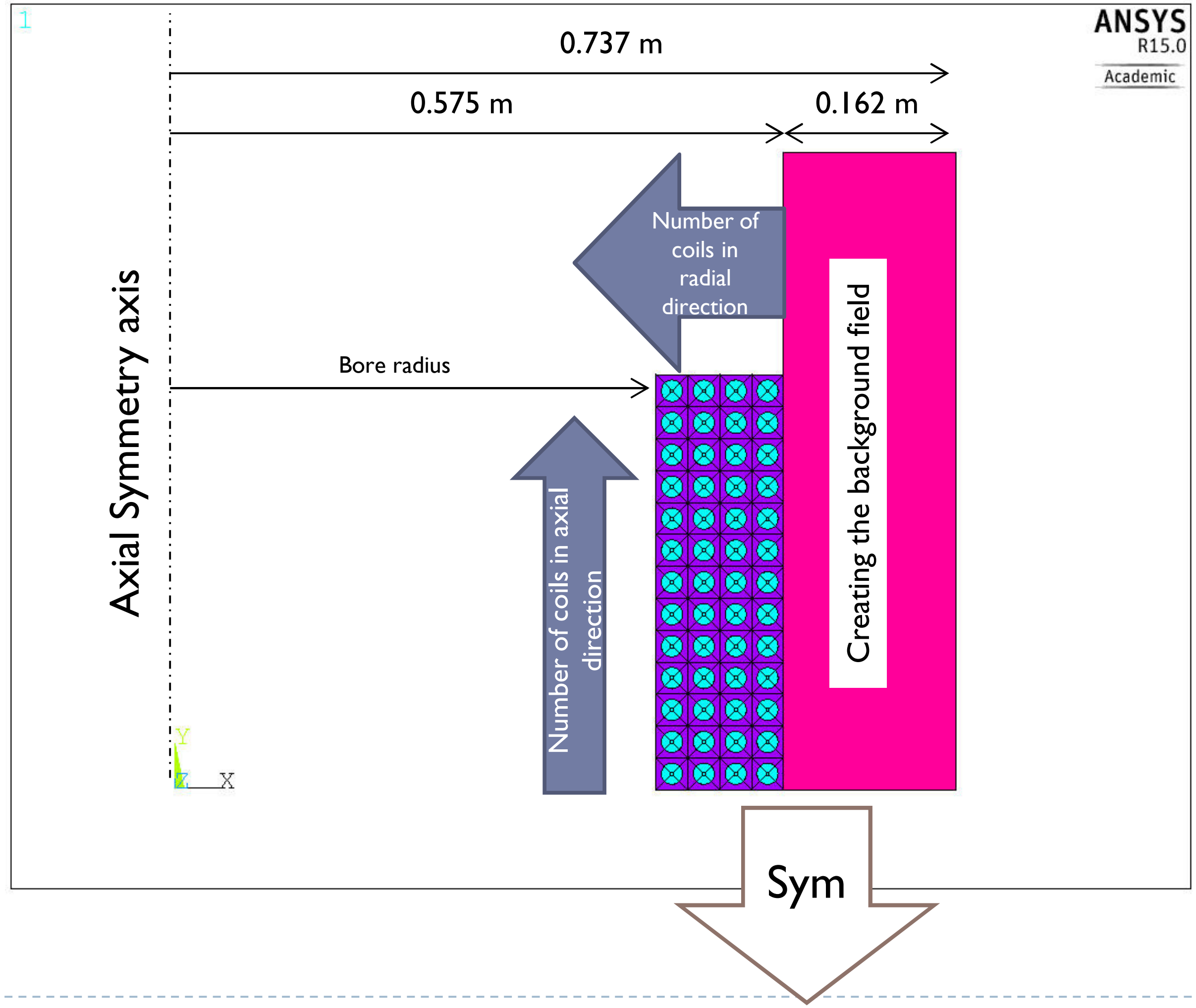
Finite element modelling

- Parametric approach taking advantage of ANSYS parametric design language (APDL)
  - 2D axial symmetric
  - Magneto-static analysis, using the magnetic vector potential (MVP), with:
    - Background field 12 T
    - Current inside the bore 22.4 KA
  - Thermo-structural analysis with loads:
    - Thermal shock (room temperature -> 4.2 K)
    - Lorentz forces, from magnetic analysis results
  - Same mesh (no interpolation needed), switching from magnetic (PLANE13) to thermo-mechanical elements (PLANE42)
  - Material properties are temperature-dependent

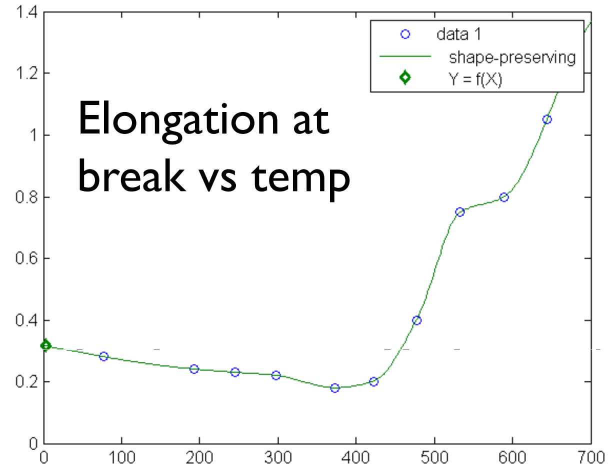
Simplified HTS cable section

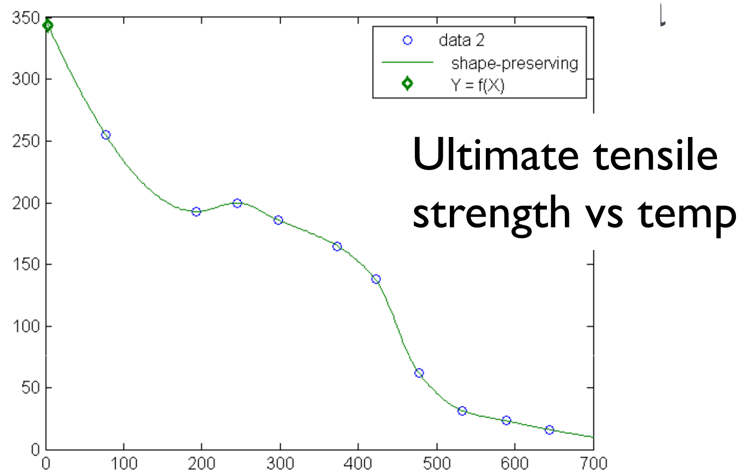


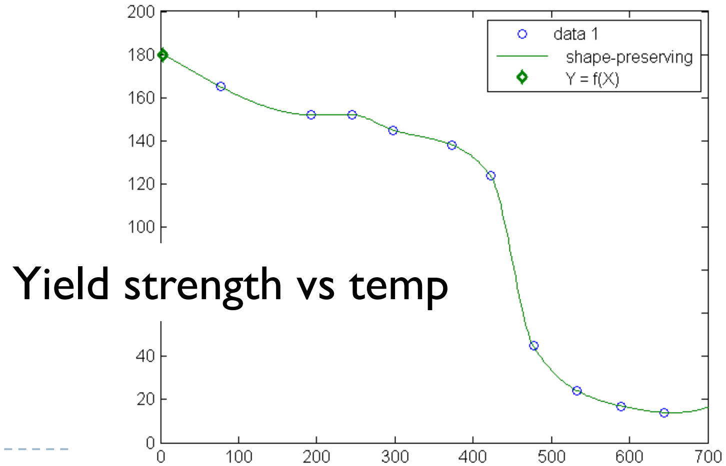
Model Parameters description

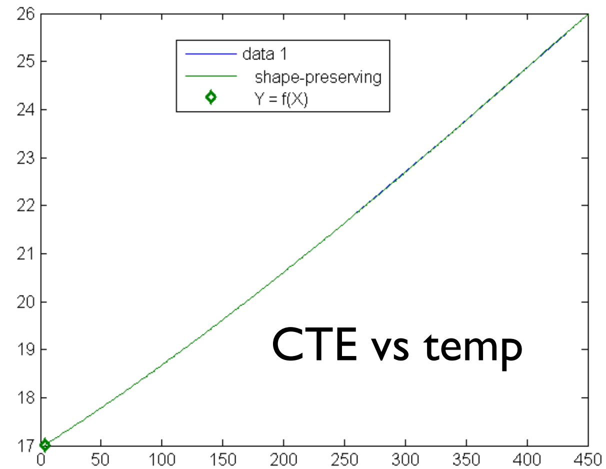


Material Properties Extrapolation (Al 6063-T5)









Trial-and-Error search approach

Number of coils in axial direction	Number of coils in radial direction	Total conductor Length [m]	**Max Field B [T]**	Bore Diameter [m]	Max Von Mises [MPa]
26	3	252	**13.7**	0.97	218
26	4	322	**14.3**	0.91	216
10	6	169	**14.1**	0.79	204
8	6	135	**13.8**	0.79	203
10	5	147	**13.8**	0.85	204
8	7	149	**14.0**	0.73	205
6	9	129	**13.9**	0.61	208
4	14	94	**13.8**	0.31	224
6	14	141	**14.9**	0.31	231
8	3	78	**13.1**	0.97	208

Mathemathical definition of optimization

Optimization is a **mathematical process** of converging onto a improved solution amongst a number of possible options, such that a set of requirements is satisfied

Find $\mathbf{X}$ to minimize (or maximize)

$F(\mathbf{X})$ objective

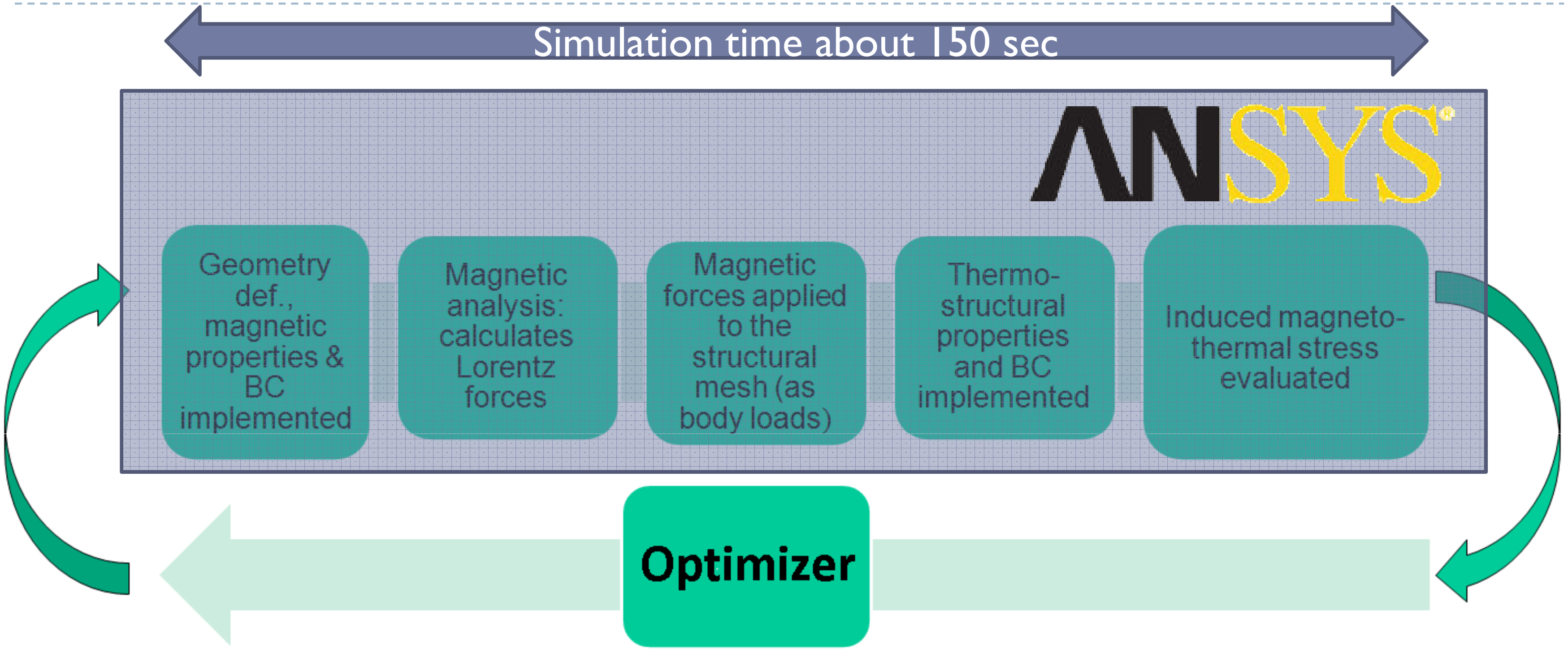
where:

$\mathbf{X} = \{x_1, x_2, \ldots, x_n\}$ design variables

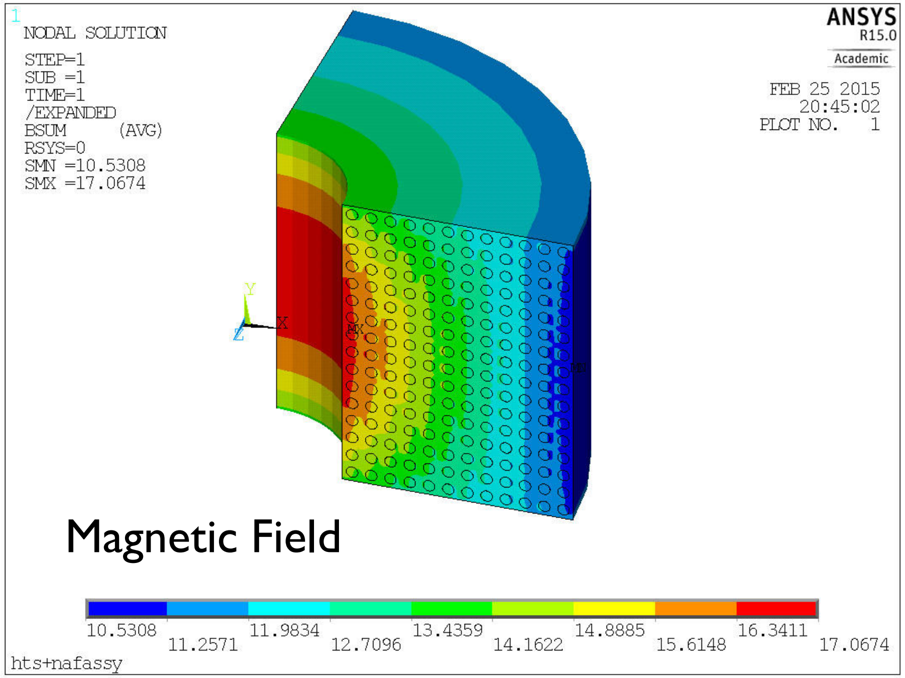
Numerical approach

- Numerical Optimization aimed to minimize the total conductor length of the high field HTS insert demonstration magnet, with:
  - Bmax ≥ 17 T (background field 12 T)
  - Design variables:
    - jacket width L [25 ÷ 40 mm]
    - Number of coils in radial and axial directions
  - Failure criteria:
    - Von Mises stress < 180 MPa (extrapolated yield)
    - literature data reports Yield at 285 MPa @7 K after hardening treatment [R.K. *Maix et al., "Design, Production and QA Test Results of the NbTi CIC Conductors for the W7-X Magnet System", Journal of Physics: Conference Series 43 (2006) 753–758*]
  - Internal bore diameter ≥ 30 cm (strain tolerance of Jc)

Optimization loop



Optimal configuration to reach 17 T



Total conductor Length = 340 m

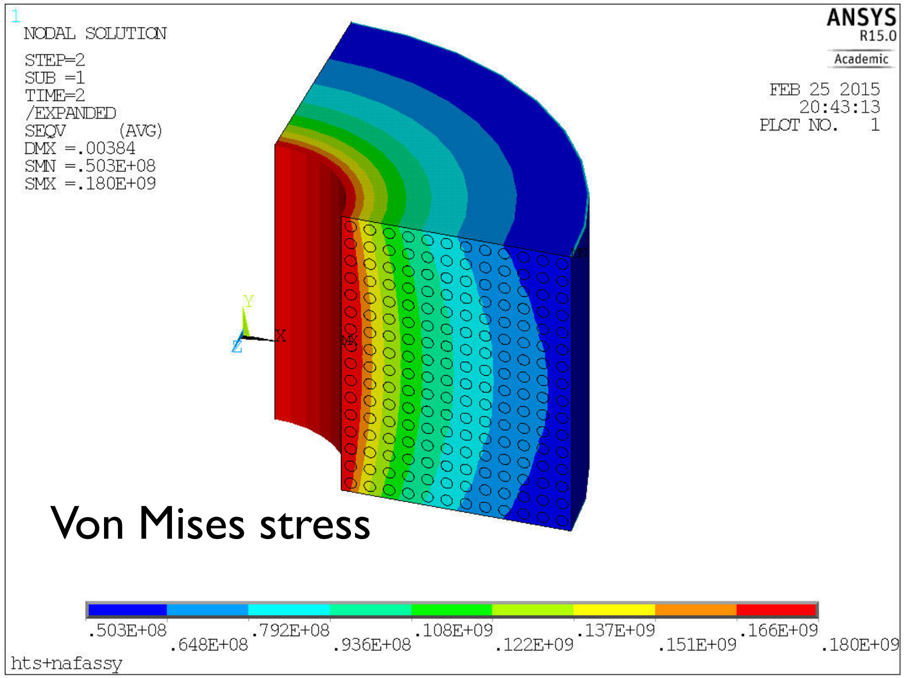
Number of coils in axial direction = 16

Number of coils in radial direction = 12

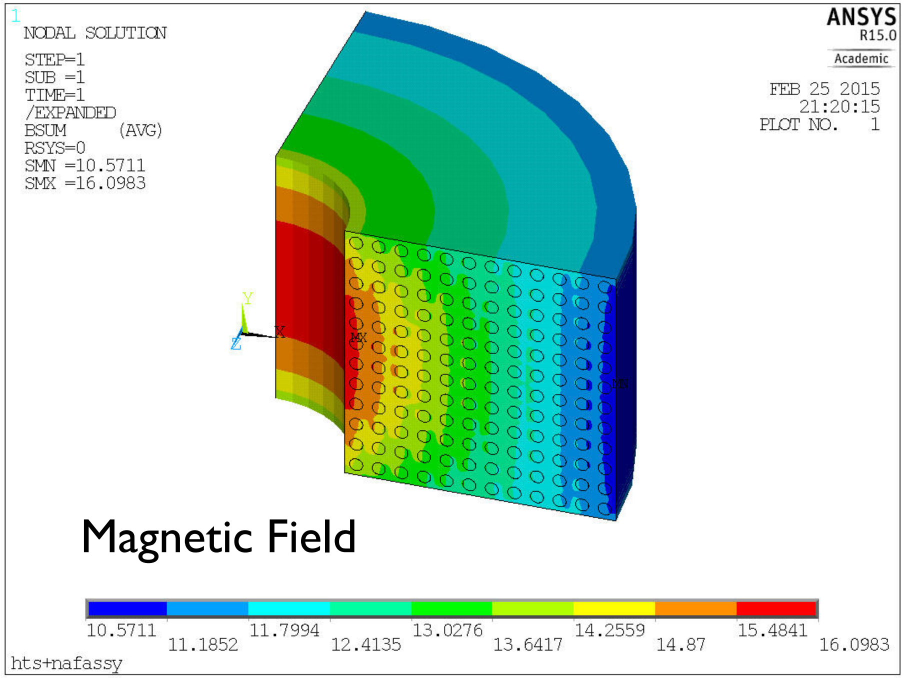
Jacket width L = 33.5 mm

Max B ≈ 17.1 T

Max Von Mises stress = 180 MPa



Optimal configuration to reach 16 T



Total conductor Length = 246 m

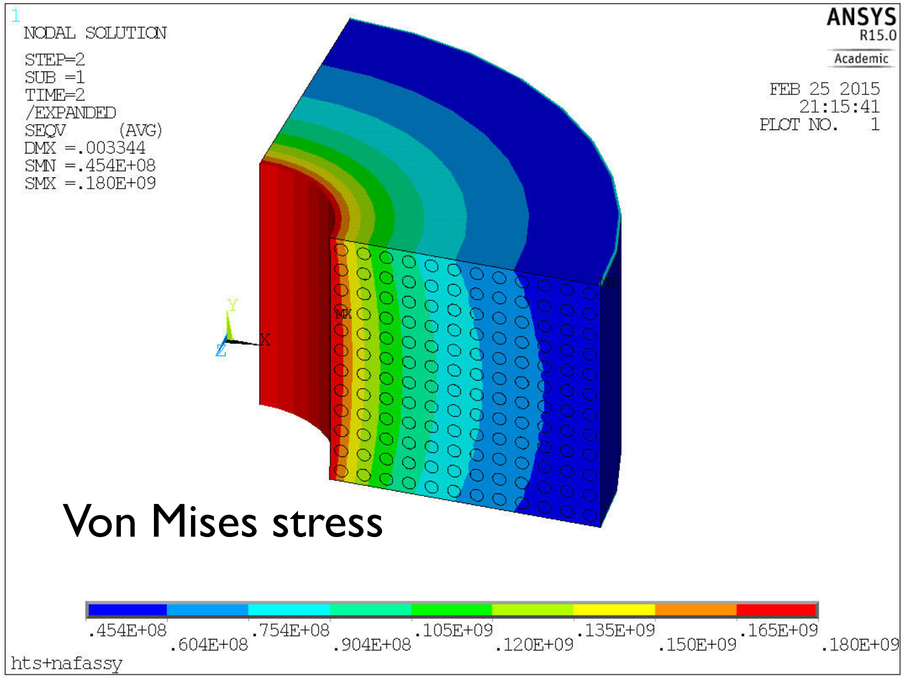
Number of coils in axial direction = 12

Number of coils in radial direction = 12

Jacket width L = 34.6 mm

Max B ≈ 16.1 T

Max Von Mises stress = 180 MPa



Conclusions

- By means of the optimization procedure, an optimal 340 m total conductor length, achieving 17 T was determined in terms of *jacket width* and *number of axial and radial coils (16 X 12 turns)*, that ensures structural integrity

- The optimization methodology is of general use and may be applied to find the minimal conductor length of high field HTS insert demonstration magnet to reach **any peak field starting from any background field**

- A scaled HTS insert coil, with a **reduced conductor length**, may be tested in the advanced experimental facility "NAFASSY" (NAtional FAcility for Superconducting SYstems) to validate the proposed metholodogy

- Thanks for your kind attention!