Magneto-Mechanical Optimization of Cross-sections for cos(ϑ) Accelerator Magnets

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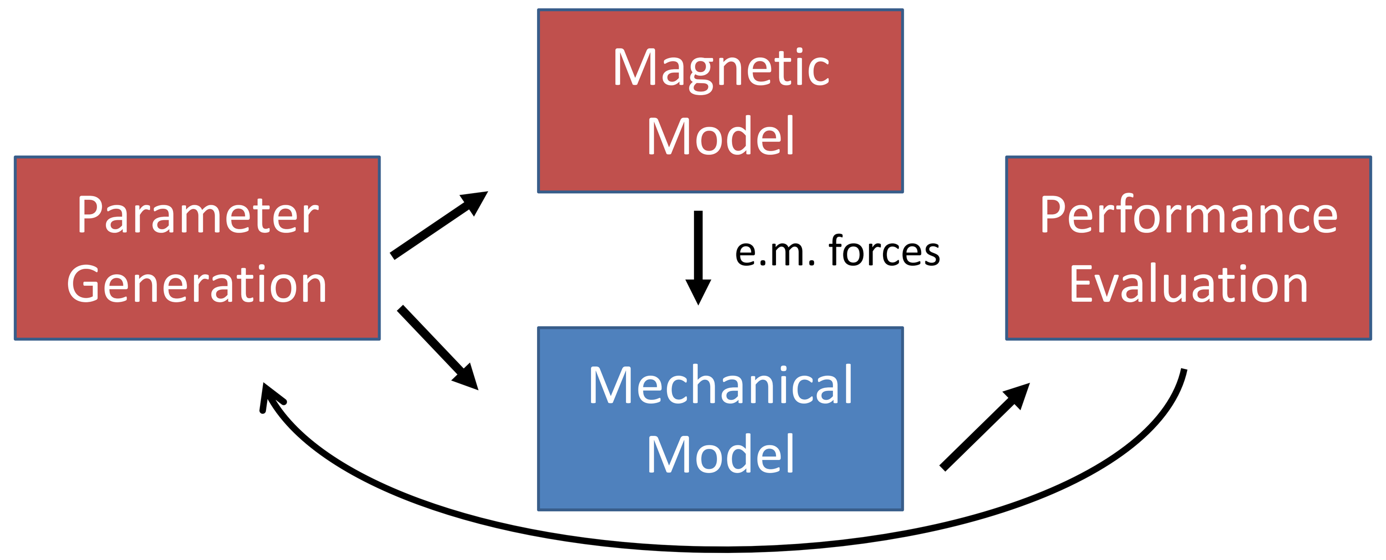
ABSTRACT

The cross-section design of cos(ϑ) superconducting magnets is historically developed in a two-step process: initially, the coil geometry is defined on the basis of magnetic optimizations; then, the structure is designed around the coil. The first step searches for the best coil cross-section maximizing the magnetic field, margin, and field quality. The latter aims at limiting the coil stresses and deformations. However, the coil design, defined in the initial magnetic optimization, can contribute to the mechanical performances of the magnet, influencing the peak stress during operation. As the critical current of every conductor is a function of the applied strain, the mechanical aspects of the coil cross-section can limit the actual magnetic performances. In this paper we propose an integrated optimization process that targets the peak stress on the conductor in addition to the magnetic objectives. The results are presented for two sample cos(ϑ) dipoles: a 2 layer and a 4 layer design aiming respectively to 15T and 16 T.

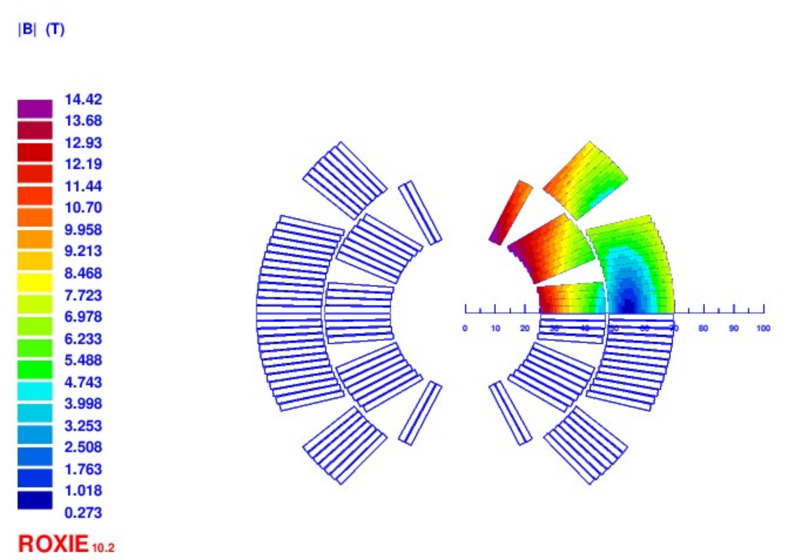
Introduction

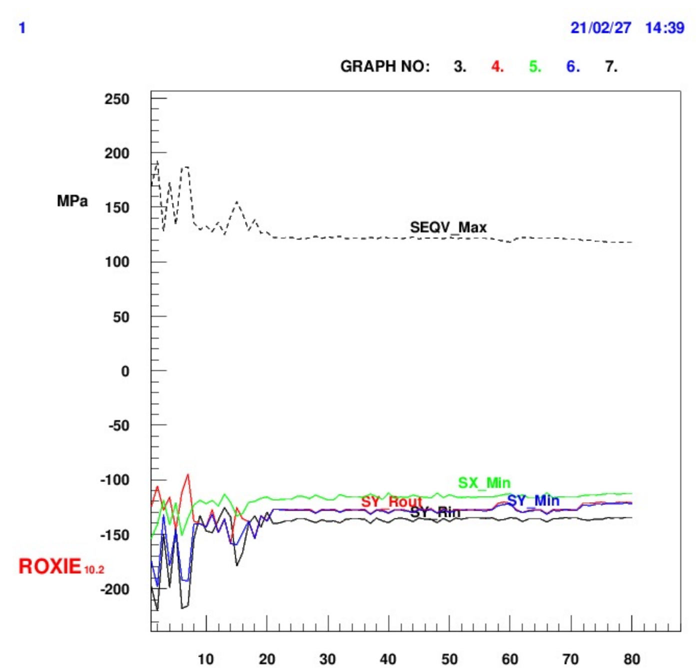
Parametric software developed in the past allowed to quickly optimize the coil cross-sections as a function of the required field and field quality. However, the coil geometry can also have an impact on the mechanical stresses. This can critically influence the performances achievable by a particular magnet.
Here we show an example joint magnet-mechanical optimization aiming at a field of 15 T on a 2 layer cos(ϑ) design.

Optimization Process and Parameters



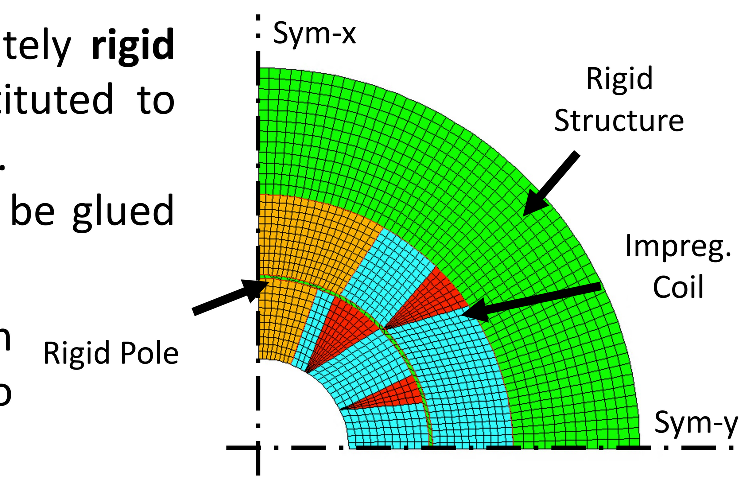
The key addition to the 'standard' magnet **design tools** is the presence of **ANSYS** in the **optimization** loop. Roxie runs the optimizer and the magnetic models, and passes to ANSYS the cross-section parameters. A **parametric APDL code** was developed to automatically compute the stresses on any cos(ϑ) cross-section during powering.





Mechanical Model Assumptions

- We assume that the **coil** is contained in an infinitely **rigid structure**. An equivalent stiffness could be substituted to introduce the effect of a particular structure design.
- The conductor is **bonded** to the **wedges**, and can be glued or not on the **interlayer**(s).
- The **coil** can **separate** from the **pole** → the solution obtained is representative of an 'unloaded' scenario for a real magnet.



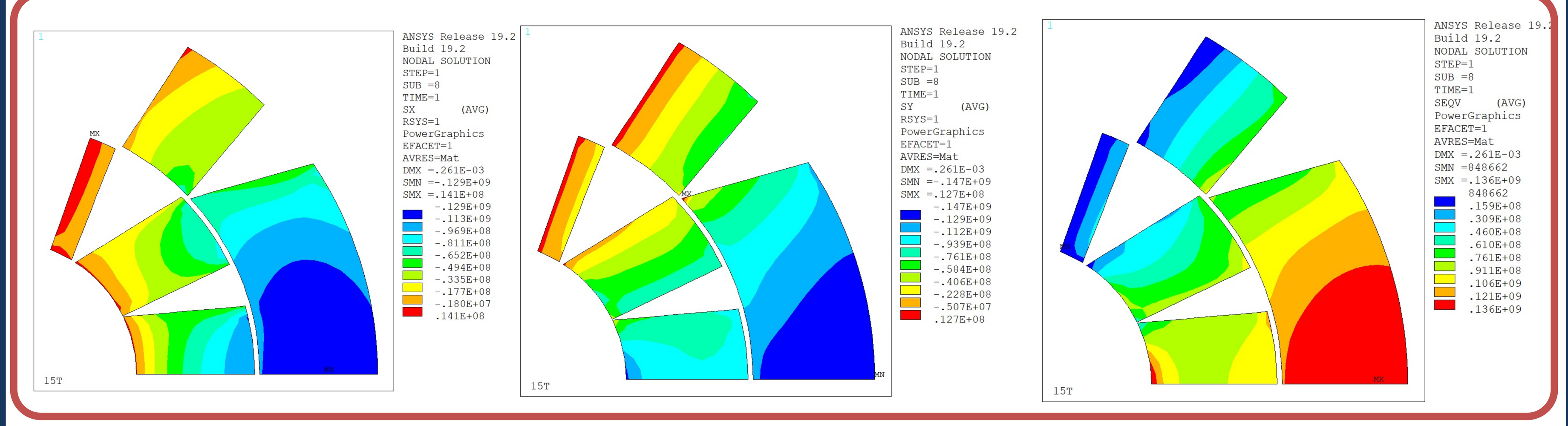
Optimization Results

Objective function 'targets': **main field**, load line **margin**, **field quality**, peak **stress**.
The **optimizer** finds the algorithm find a **10% stress reduction** with similar field quality to a pure magnetic optimization. Multiple solutions with similar maximum stress exist.

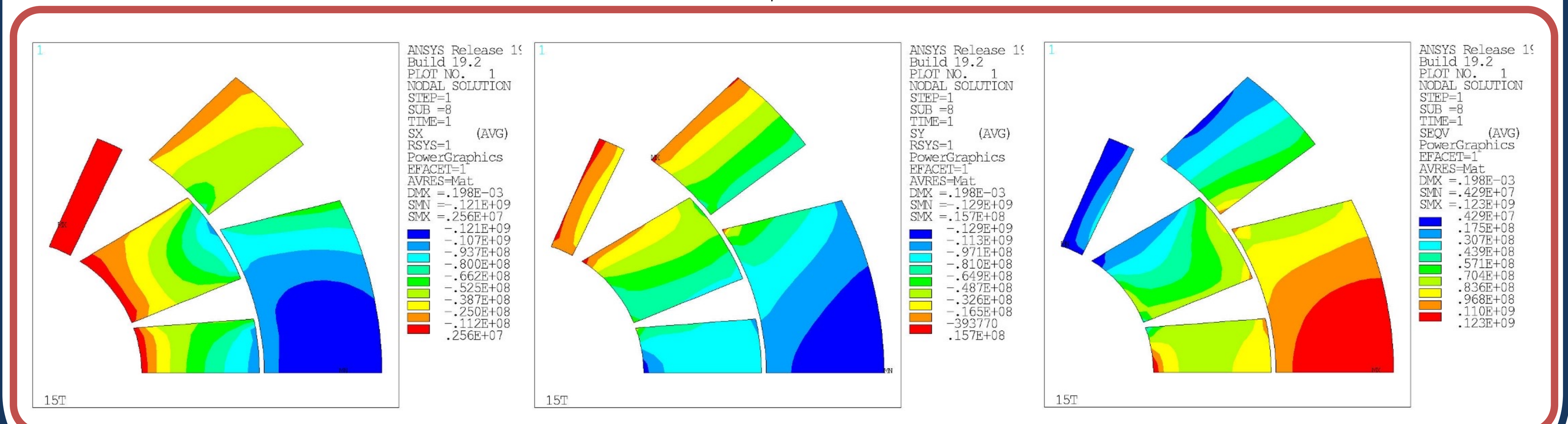
Max. stress at 15 T (e.m. optimization → combined optimization):

- Radial: 129 MPa → 121 MPa
- Azimuthal: 147 MPa → 129 MPa
- Von Mises eqv.: 136 MPa → 123 MPa

Magnetic optimization



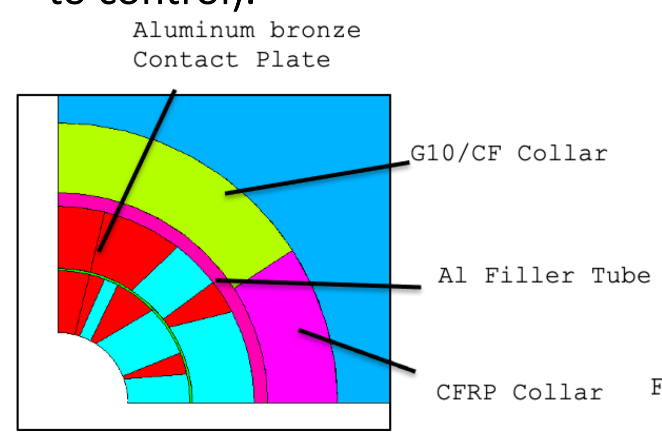
Combined optimization

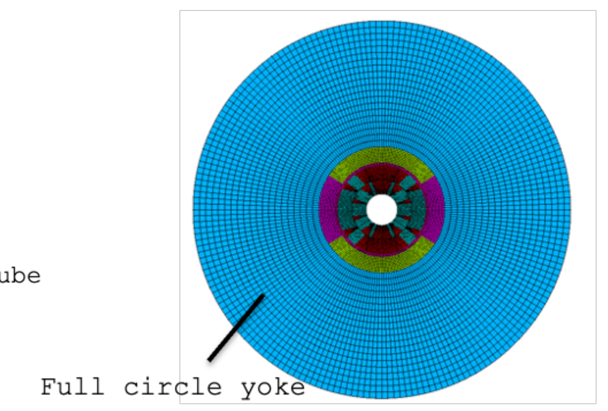


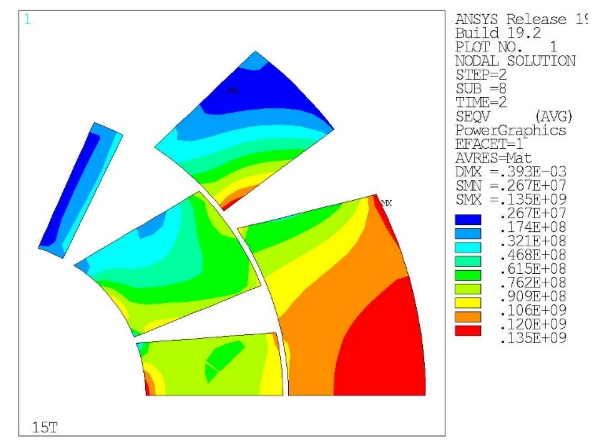
Effect of the Mechanical Structure

The **deformability** of the **structure** can increase significantly the **stresses** on the coil. This is mostly due to the **bending** of the coil, which tends to become an **ellipse** with the major axis on the x-axis. We tried to design a structure which would **limit** this effect by making it 'easier' to move on the minor axis of the ellipse. Main features:

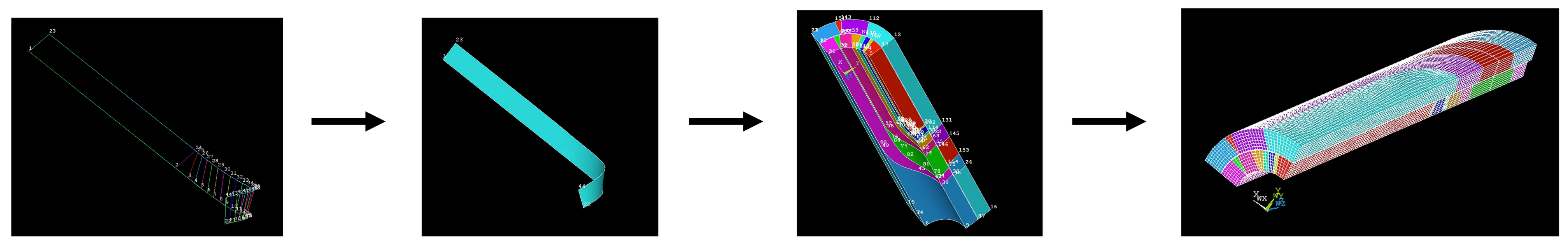
- **Al. tube** around the coil pack – Good contact everywhere after cooldown
- **CFRP collar** to close the gap between the yoke and the tube (radial fibers).
- **G10 collar** (might be CF), not glued to the other collar part
- **Yoke closed** at all times (for stiffness). Or, to enable **prestress**, **closing** during **cooldown** (difficult to control).







3D Optimization



What about the **magnet ends**? How much the **stress** and **contact pressures** are dependent on the **geometry**? Can we develop an **automatic tool** to quickly test different coil shapes?
The first step is creating an automatic mesher from coil parameters:

Roxie CNC lines → ANSYS keypoints → Bsplines → Surface patches → Solid shapes

Conclusions

- The combined **magneto-mechanical** optimization allows to **reduce** (10% in the shown case) the **coil stress** during **powering**
- The results highlight two main features of the 'optimal' solutions:
  - **Wedges** are positioned on the middle of the coil block. This increases the stiffness, reducing the total bending of the coil (which can generate a peak stress on the inner radius).
  - When possible, wedges are aligned so that the **radial stress** can 'flow' towards the structure

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