Vittorio Di Marzo

Mechanical and Electromagnetic modelling for Controlled Thermonuclear Fusion

Tutor: Prof. Roberto Ambrosino

Cycle: XXXVIII Year: Second

Year End Presentation (YEP) - 07/11/2024 – University of Naples Federico II

My background

- MSc degree in Mechanical Engineering for Design and Production (July, 2022)
- Research group/laboratory: DIETI Plasma Control Group
- PhD start date: 01/11/2022
- Scholarship type: PNRR - DM 352
- Partner company: Eni S.p.A.
- Periods abroad: 5 months at Fusion For Energy (Barcellona) (currently spending the 6th month)

Summary of study activities

- **Courses borrowed from MSc curricula:**
  - Modellistica e dinamica dei campi (9 CFU)
- **Ad hoc PhD courses / schools:**
  - Advanced Control on plasma control and CODAC (6 CFU)
  - Strategic orientation for STEM research & writing (type B)
  - 4TH International School On Numerical Modelling for Applied Superconductivity
  - Scuola Nazionale Dottorandi di Elettrotecnica “Ferdinando Gasparini”

Research area

- **Controlled Thermonuclear Fusion**
- The process involves two light atomic nuclei **combining** to form a single, heavier nucleus, releasing a huge amount of energy in the process. These fusion reactions occur in a state of matter known as **plasma**, within a device referred to as **"Tokamak"**.

Problem (one of many)

- Huge electromagnetic loads

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- Huge mechanical stresses

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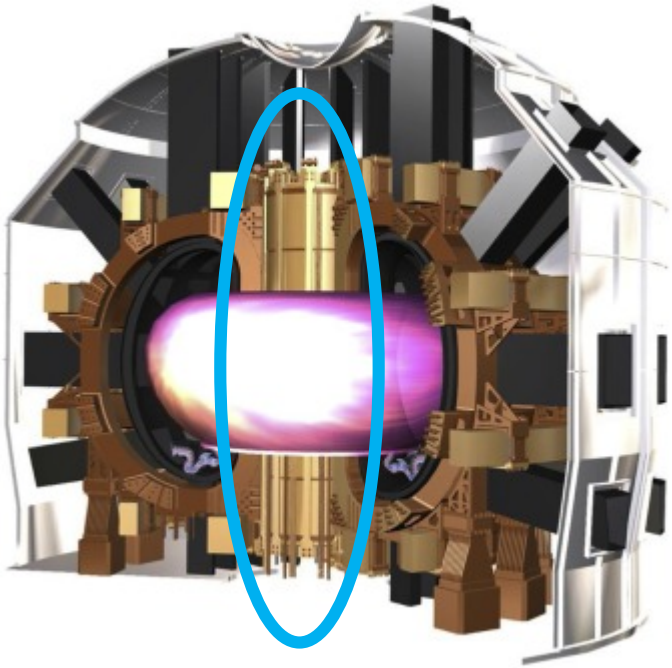
- Critical component: Central Solenoid (CS)



Research area

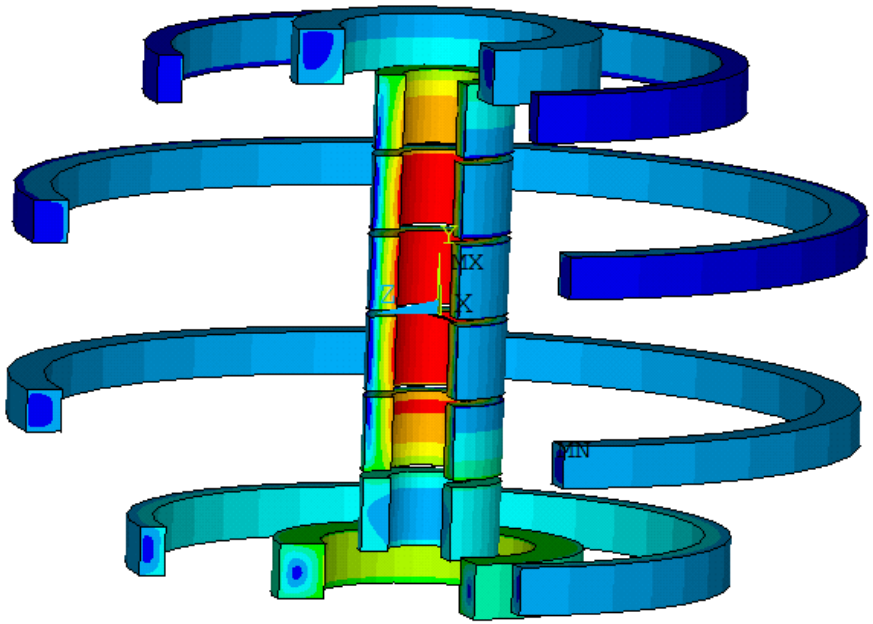
- **Focus: Electromagnetic and mechanical modelling of the Central Solenoid (CS) in the DTT tokamak**
- **Current design:**
  - **Low-Temperature** Superconductors (LTS)
- **Key challenge:**
  - Mechanical stresses due to huge electromagnetic loads
- **Objective of my research** (currently in **Fusion For Energy (BCN)**, under the supervision of Dr. Alfredo Portone, Dr. Pietro Testoni, Dr. Jose Lorenzo):
  - Validation of current electromagnetic and mechanical results
  - Exploration of an alternative design with **High-Temperature** Superconductors
    - **Advantage**: Greater structural rigidity, improved electromagnetic performance
- **In the following slides:** Electromagnetic and mechanical design procedure (the results are referred to the current design)

Electromagnetic and Mechanical modelling for the DTT's CS

- **Step 1: Electromagnetic analyses:**

- To reach higher induced fluxes to the plasma, in the **current** configuration, **Low - Temperature** Superconductors (LTS) have been used

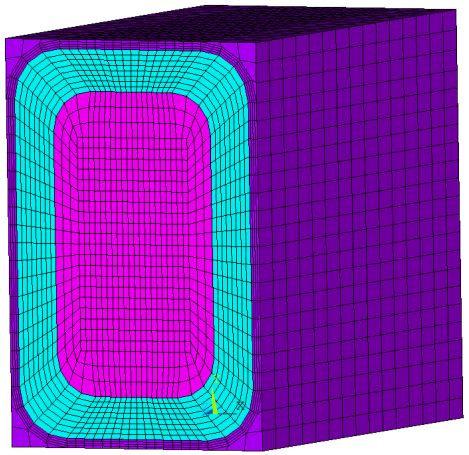
- FEM analyses have been developed to get:
  - **Azimuthal Potential Vector** in each node of the mesh
  - **Electromagnetic Forces** in each CS's module



Distribution of **the total magnetic flux density** in a certain time instant

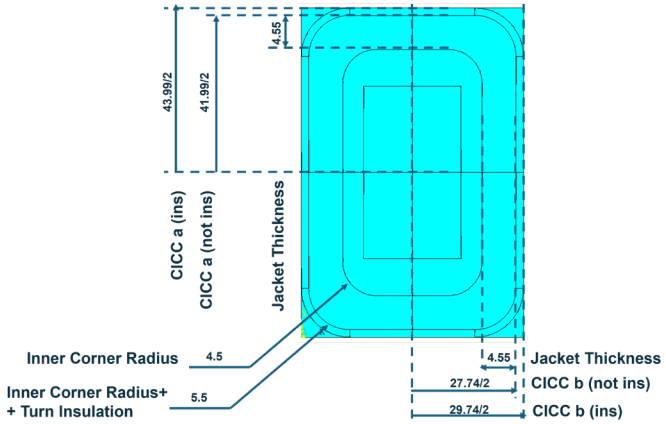
Electromagnetic and Mechanical modelling for the DTT's CS

- **Step 2: Mechanical analyses 1/2:**



- Since the moment that several hundreds of superconductors are used, to reduce the computational burden, equivalent material properties have been evaluated

- In this way, the CS will be modeled with equivalent homogeneous blocks;
- Once the most stressed block is identified, only that will be modeled in detail



Detail of the used conductor for the innermost region of the CS

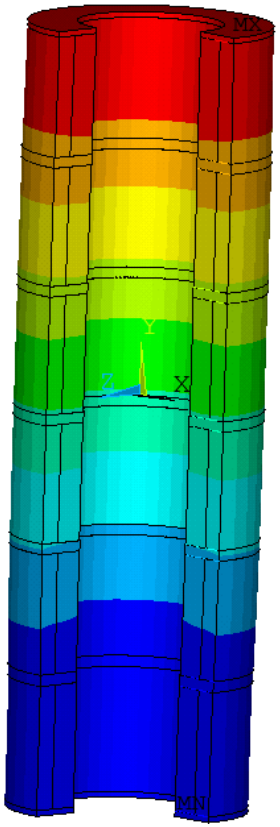
Electromagnetic and Mechanical modelling for the DTT's CS

- **Step 3: Mechanical analyses 2/2:**

➢ Using the electromagnetic forces derived in the step 1 as loads + a precompression force to avoid separations between the modules, mechanical analyses have been developed

➢ The following data are extracted for the following analyses:

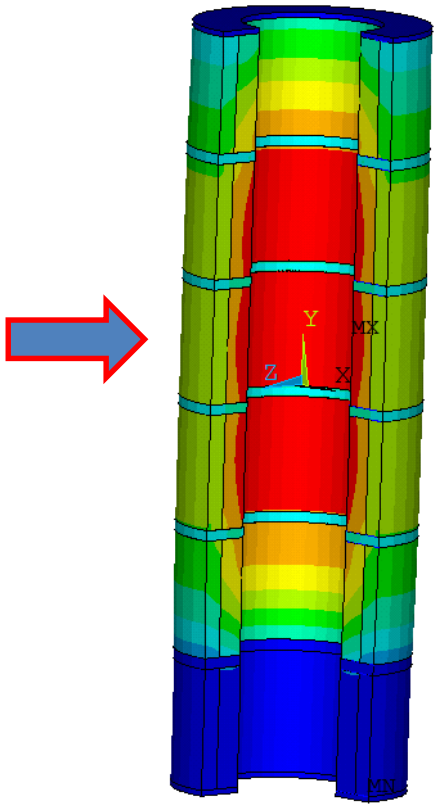
  ➢ **Displacements** in each node of the mesh



Distribution of the **total displacement field** in a certain time instant

Electromagnetic and Mechanical modelling for the DTT's CS

- Examining the distribution of the stresses, it is possible to identify the **most stressed module** and to model it in detail

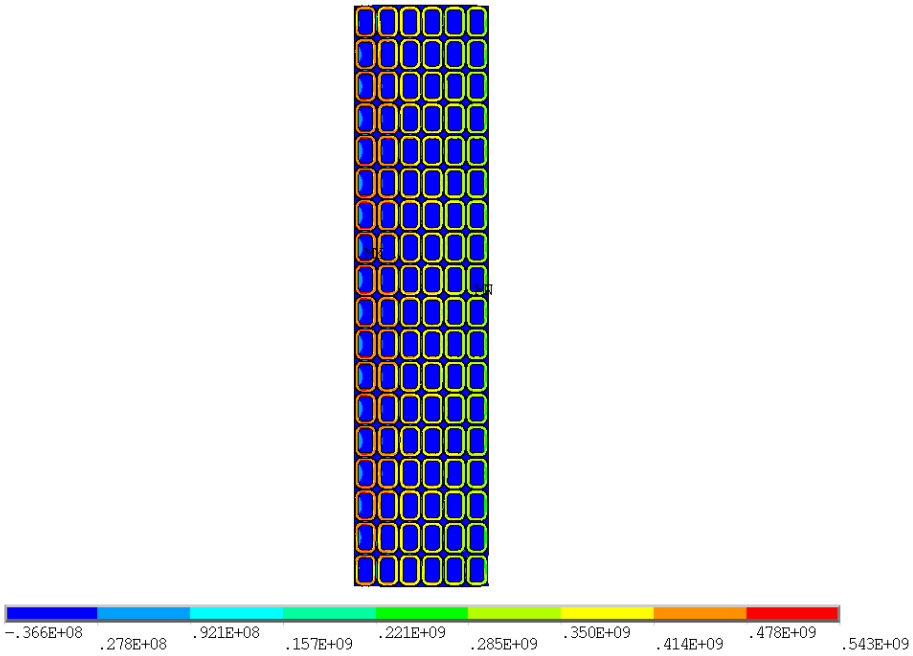


Distribution of the **equivalent stresses** in a certain time instant

Electromagnetic and Mechanical modelling for the DTT's CS

- **Step 4: Local analyses (EM and mechanical):**

➢ Once **azimuthal potential vector** and **displacements** are known for each node, they can be used as Boundary Conditions to develop **local** detailed analyses of the conductors of the most stressed module



Distribution of **Tresca's equivalent stresses** in a certain time instant for the innermost region

Research results

- **Results of the several analyses:**

- Too much high mechanical stresses
- Thermohydraulic problems with the temperature margin of the superconductors

- Explorative analyses with **High Temperature Superconductors (HTS)** (currently in progress)

Research products

[P1]	R. Ambrosino, V. Di Marzo et al. "DEMO in-vessel equatorial coils for power-exhaust and fast plasma control", **Fusion Engineering and Design**, Volume 197, 2023
[P2]	F. Romanelli, V. Di Marzo et al., "Divertor Tokamak Test facility Project: status of design and implementation", **Nuclear Fusion**, Volume 64, 2024
[P3]	F. Maviglia, V. Di Marzo et al., "Studies on EU-DEMO In-Vessel Coils requirements and conceptual design for axisymmetric plasma control", **49th EPS Conference on Plasma Physics**, 2023
[P4]	E. Acampora, V. Di Marzo et al., "Scenario feasibility and plasma controllability for Volumetric Neutron Source (VNS)", **33rd Symposium on Fusion Technology (SOFT)**, Dublin, September 2024 (paper to be submitted but already presented)
[P5]	A. Castaldo, V. Di Marzo et al., "Electromagnetic feasibility studies of plasma scenarios of DTT tokamak", **33rd Symposium on Fusion Technology (SOFT)** , (paper to be submitted, but already presented)

Next year's activities

- Research of suitable HTS superconductors for explorative analyses
- Research on HTS superconductive properties
- Further analyses on DTT's CS with Low-Temperature Superconductors
- Development of an hybrid model with Low temperature and High temperature superconductors