WPMAG – CEA IRFM
Electromagnetic analysis

14/01/2025

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2025 CEA TS
Electromagnetic analysis

MAG-S.01.01-T029 - D001

2025 CEA electromagnetic calculations

TS Title:	2025 CEA electromagnetic calculations
TS Ref. Nr.:	MAG-S.01.01-T029
Status:	In review

Deliverables of the task:

Deliverable	Description
MAG-S.01.01-T029 - D001	*Activities will include the effective magnetic field calculations on the hybrid HTS/LTS and ITER-like CS designs on the 2025 update. It will also include the 2025 update of the TF WP#4 design, with the contribution of the PF coils from the new baseline.*

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Electromagnetic analysis

In 2024, we reported on the EMag analysis of TF/CS magnets for LAR Baseline 2024.

Since no major change has been adopted in 2025, we focused on complementary analyses.

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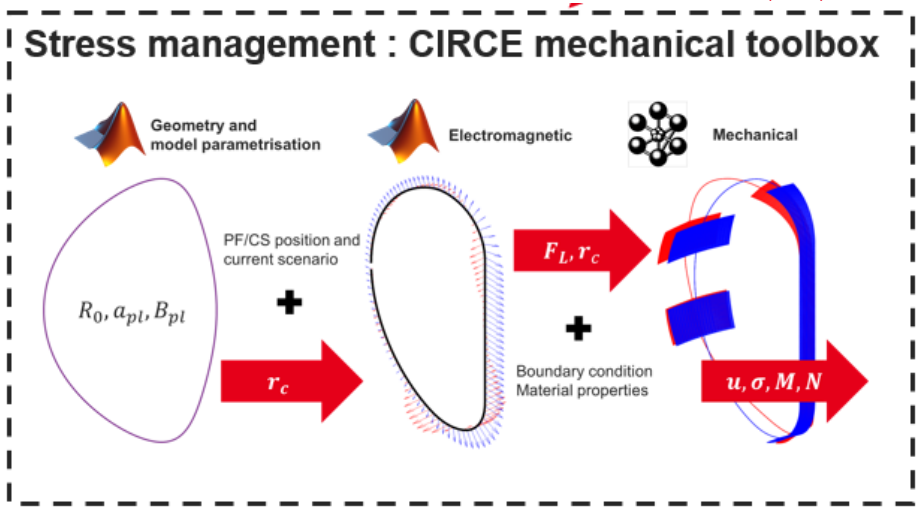
Electromagnetic analysis



CIRCE: Geom/EMag/Mech Toolbox

At CEA, there is a new tool developed by Baptiste Boudes, for:

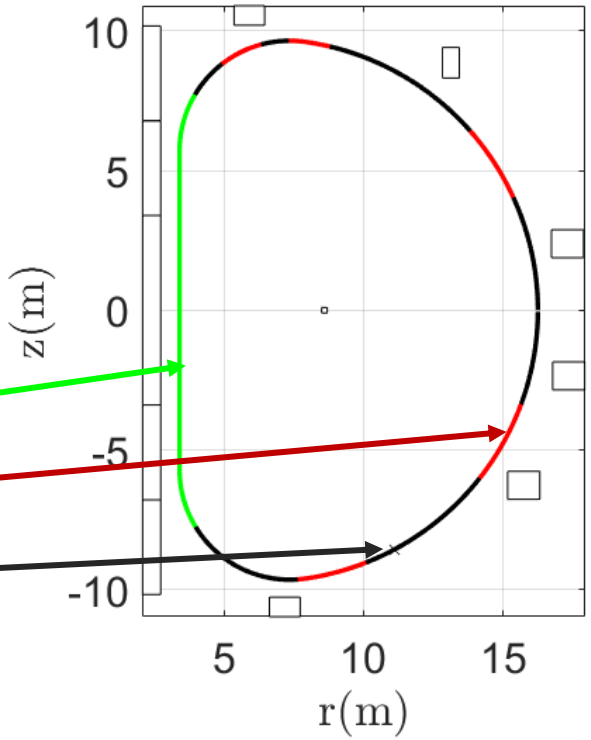
- Geometrical analyses
- Electromagnetic analyses
- Loads computation
- Mechanical pre-design

The DEMO LAR CIRCE Model was built

Geometrical analyses: General coil Trajectory

Definition of portions:

- Wedged interface
- OIS interfaces
- Gravity support



2025 CEA TS Electromagnetic analysis

CIRCE: Geom/EMag/Mech Toolbox

Inductance of full tf system ($I_{cable} = 68kA$) Inductance of full tf syste ($I_{cable} = 82kA$)	41.6 H 28.5 H
Total stored magnetic energy	96.19 GJ
Net radial force	-736,64 MN
Vertical force on upper half coil	358,56 MN
Max overturning moment on one coil	506,88 MN.m

Main Electromagnetic results:

Full TF System Matrix inductances ----------->(N_{turns}^{1coil})^2

1.4E-03	Coil1	Coil2	Coil3	Coil4	Coil5	Coil6	Coil7	Coil8	Coil9	Coil10	Coil11	Coil12	Coil13	Coil14	Coil15	Coil16
Coil 1	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05
Coil 2	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06
Coil 3	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06
Coil 4	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06
Coil 5	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06
Coil 6	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06
Coil 7	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07
Coil 8	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07
Coil 9	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07
Coil 10	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06
Coil 11	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06
Coil 12	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06	2.0E-06
Coil 13	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06	3.3E-06
Coil 14	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05	5.7E-06
Coil 15	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05	1.1E-05
Coil 16	1.1E-05	5.7E-06	3.3E-06	2.0E-06	1.4E-06	1.0E-06	8.6E-07	8.0E-07	8.6E-07	1.0E-06	1.4E-06	2.0E-06	3.3E-06	5.7E-06	1.1E-05	3.4E-05

28.5	Coil1	Coil2	Coil3	Coil4	Coil5	Coil6	Coil7	Coil8	Coil9	Coil10	Coil11	Coil12	Coil13	Coil14	Coil15	Coil16
Coil 1	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01
Coil 2	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01
Coil 3	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02
Coil 4	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02
Coil 5	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02
Coil 6	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02
Coil 7	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02
Coil 8	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02
Coil 9	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02
Coil 10	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02
Coil 11	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02
Coil 12	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02	4.2E-02
Coil 13	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01	6.7E-02
Coil 14	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01	1.2E-01
Coil 15	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01	2.3E-01
Coil 16	2.3E-01	1.2E-01	6.7E-02	4.2E-02	2.9E-02	2.1E-02	1.8E-02	1.7E-02	1.8E-02	2.1E-02	2.9E-02	4.2E-02	6.7E-02	1.2E-01	2.3E-01	7.1E-01

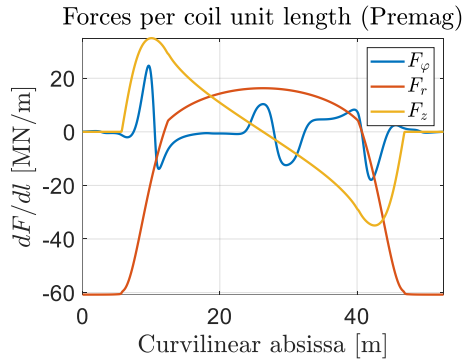
Here for Icable=82kA, Nturns=144

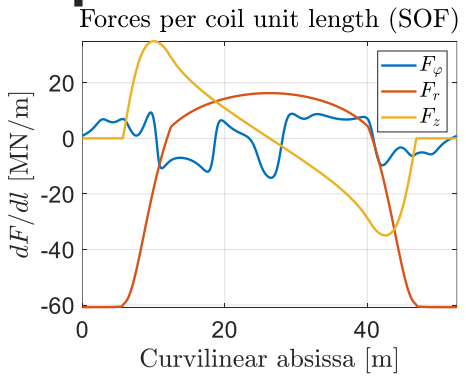
2025 CEA TS
Electromagnetic analysis

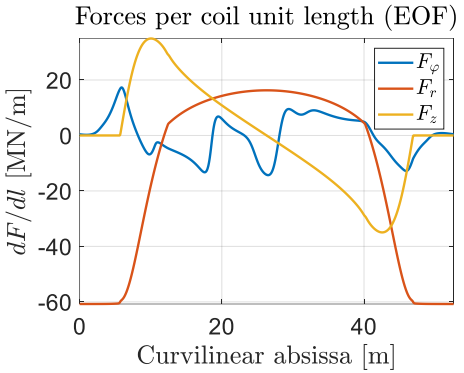
CIRCE: Geom/EMag/Mech Toolbox

Main Electromagnetic results: Load computation

CIRCE







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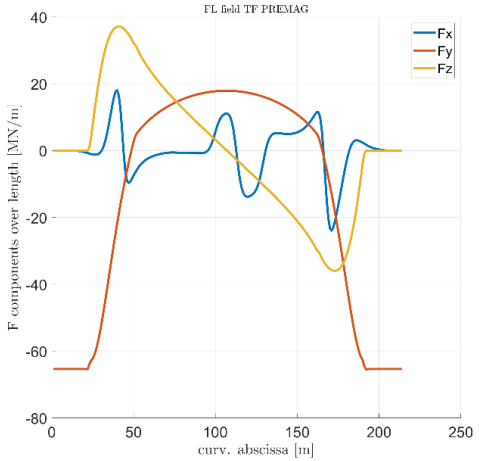
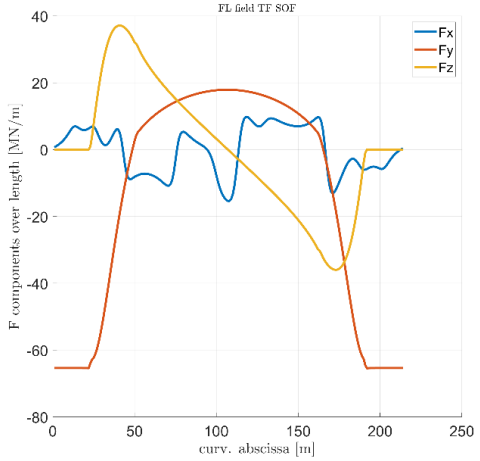
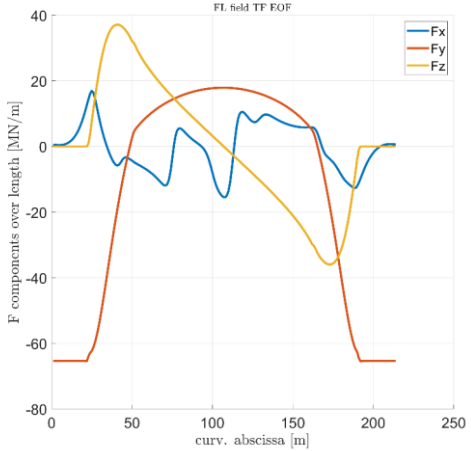
3DFEM



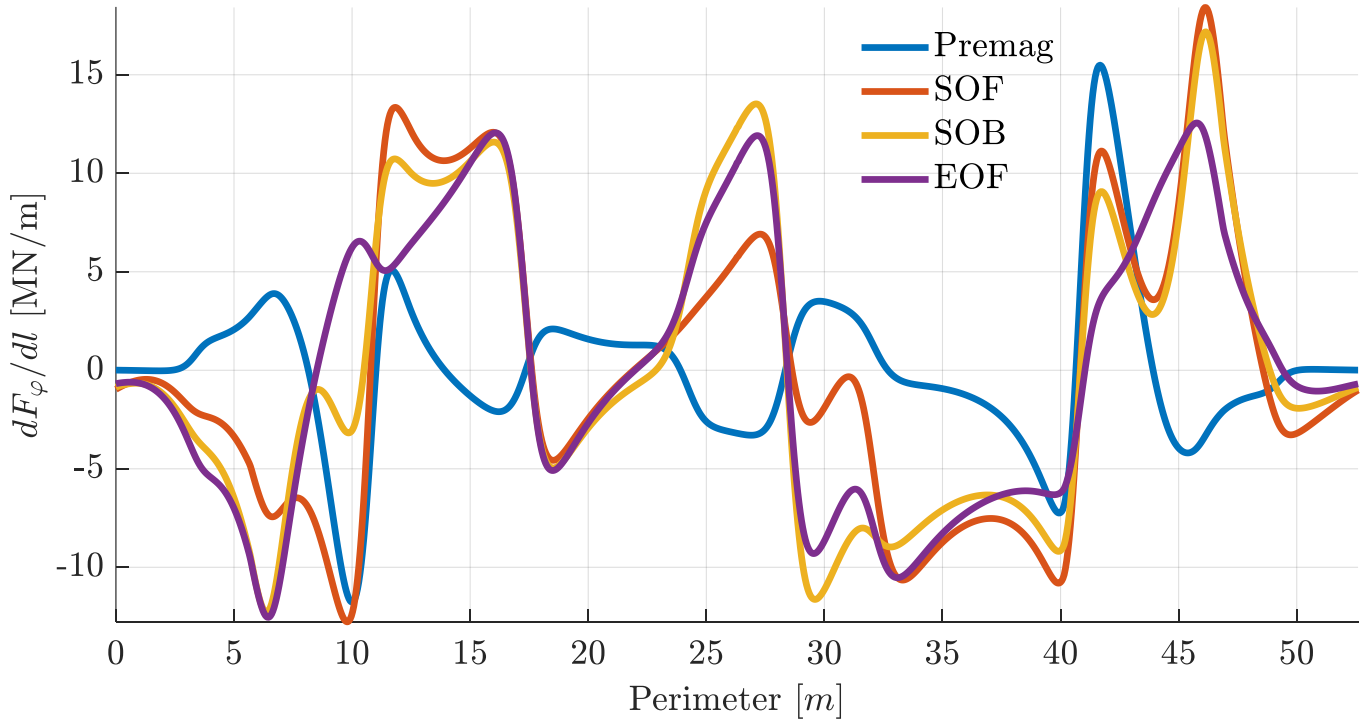


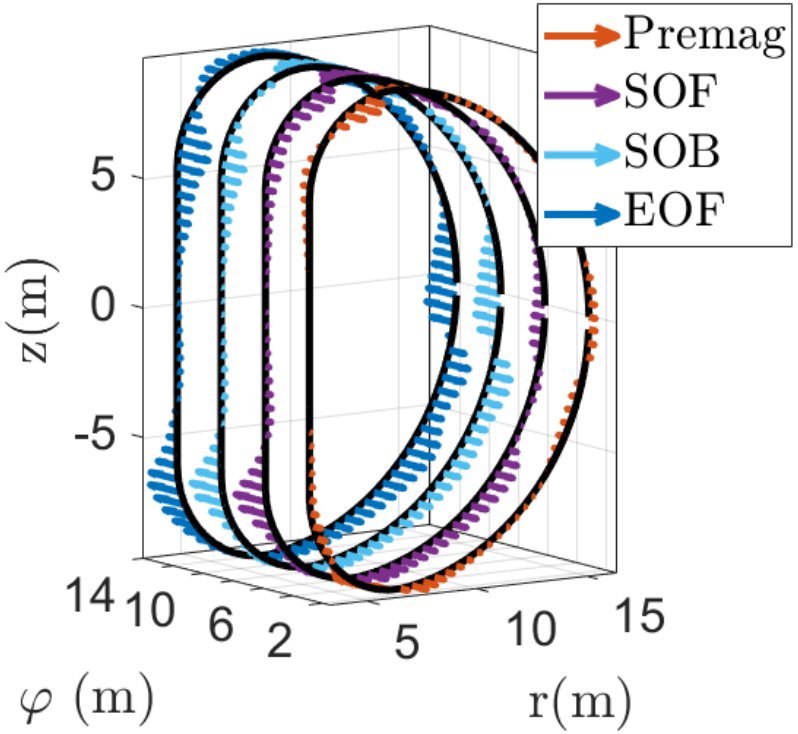


2025 CEA TS
Electromagnetic analysis

CIRCE: Geom/EMag/Mech Toolbox

Main Electromagnetic results: Load computation – OUT OF PLANE

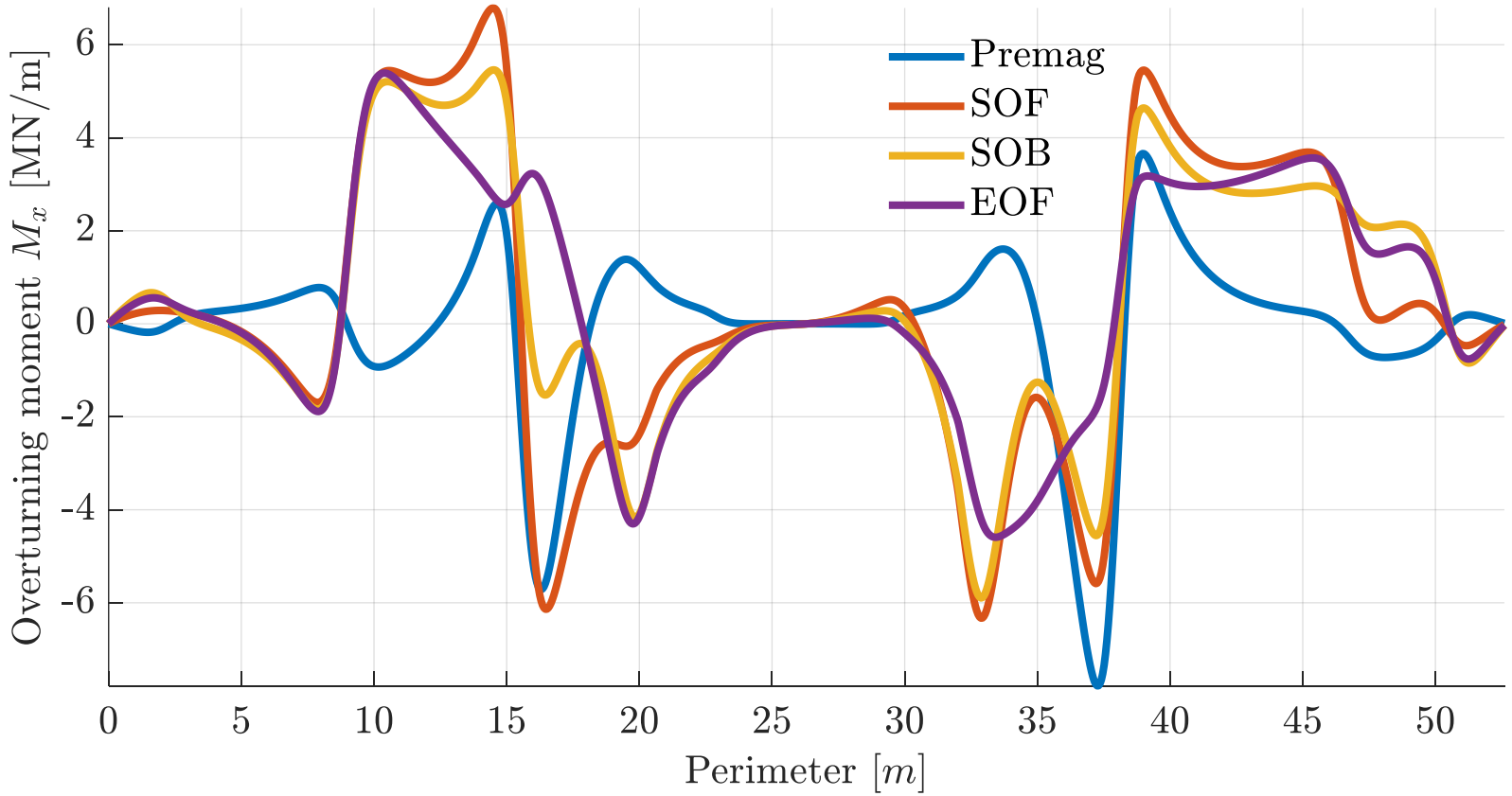




2025 CEA TS
Electromagnetic analysis

CIRCE: Geom/EMag/Mech Toolbox

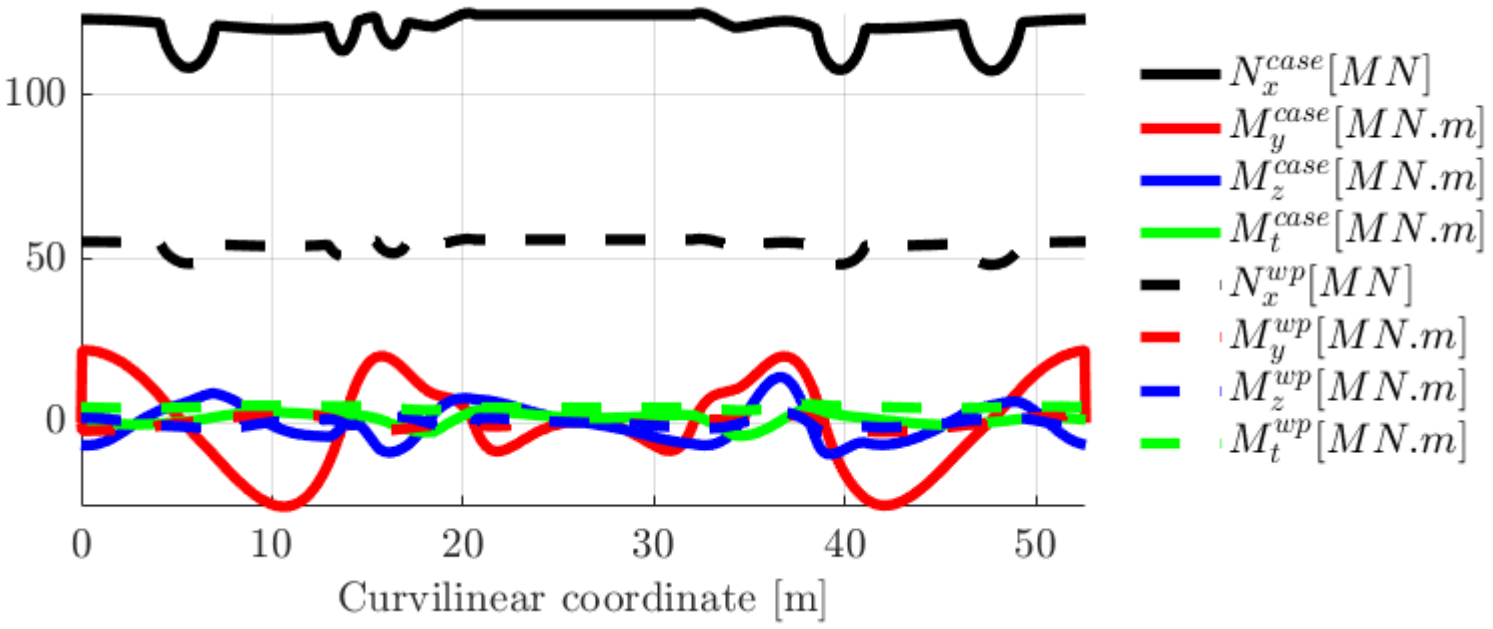
Main Electromagnetic results: Load computation - OVERTURNING MOMENT

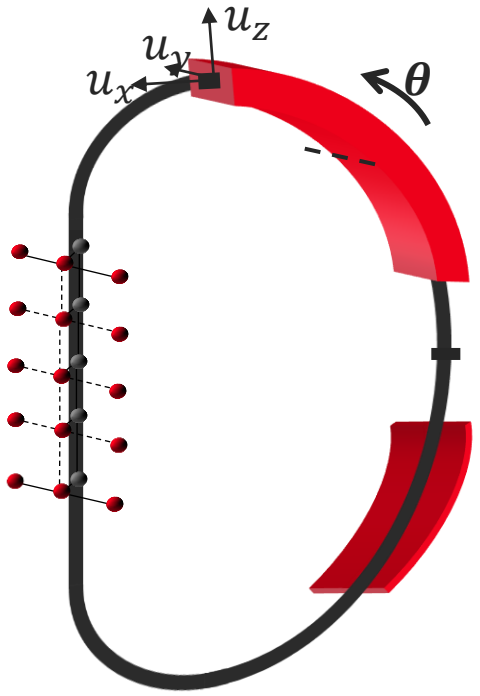


2025 CEA TS
Electromagnetic analysis

CIRCE: Geom/EMag/Mech Toolbox

The CIRCE Model has been used to provide the 3D mechanical model with 3D load maps, and can also run some mechanical analyses which will be included in 2025 reports (Design, EMag or Mechanical to be defined).





2025 CEA TS
Electromagnetic analysis

FSD of TF magnet and induced currents

The total energy stored in the TF system is $E_{mag} = 96GJ$

A [**Case-RP-VV-Coil**] coupled system was built based on best inputs available, and the FSD is triggered to compute the induced currents in all components, along with heat generated.

$L_{TF}^{system} = 28.5H$

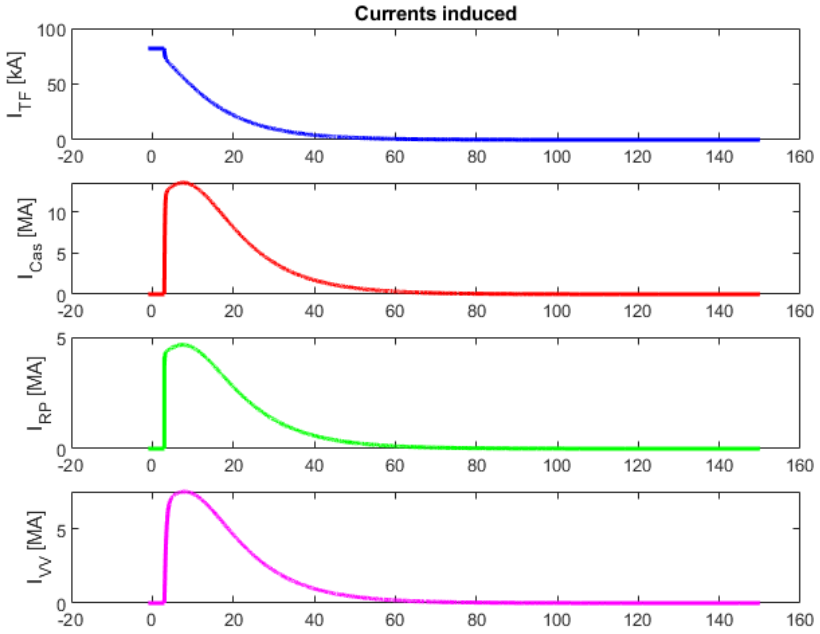
Discharge time constant is based on the VV requirements

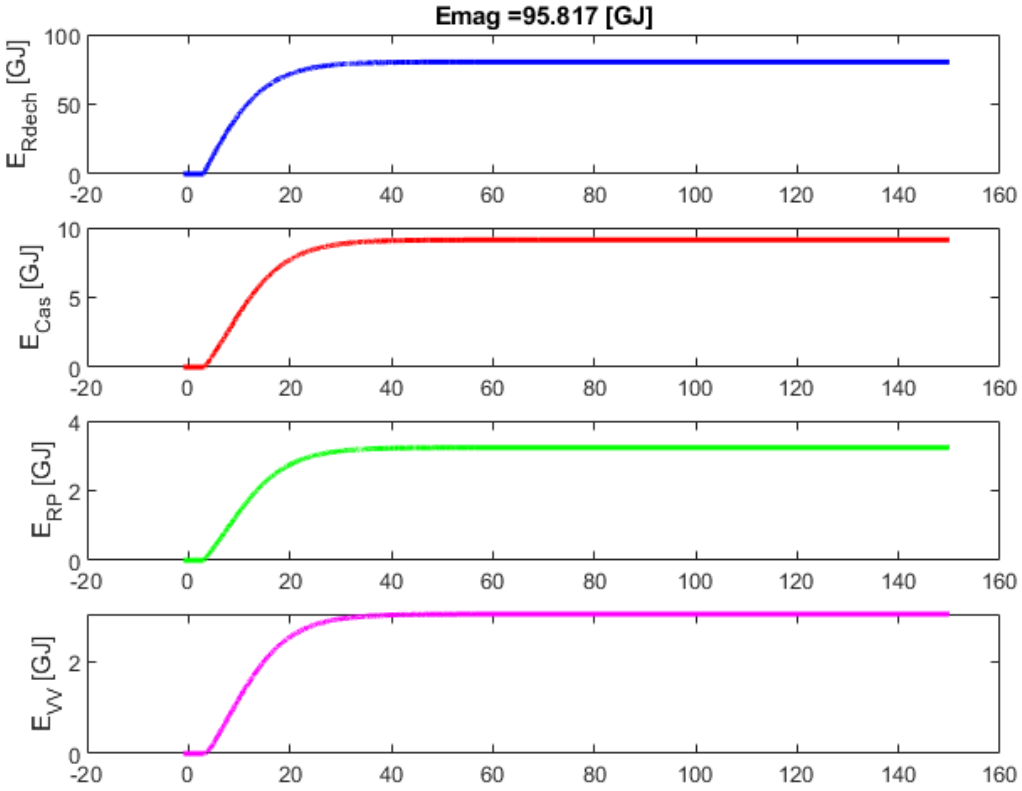
$$\tau_{dis} = 22s$$

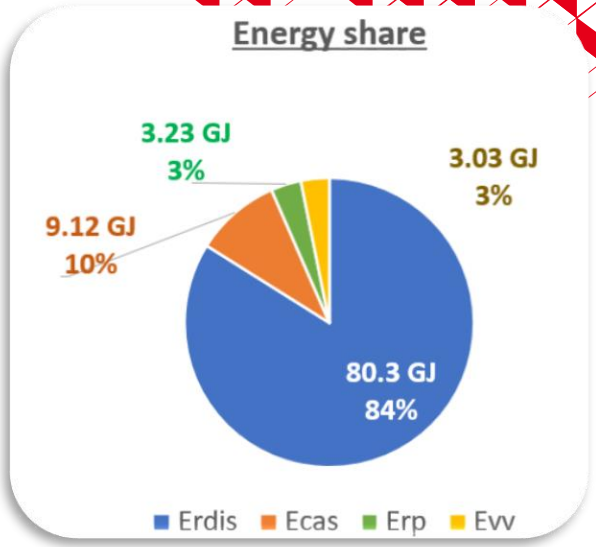
2025 CEA TS
Electromagnetic analysis

FSD of TF magnet and induced currents

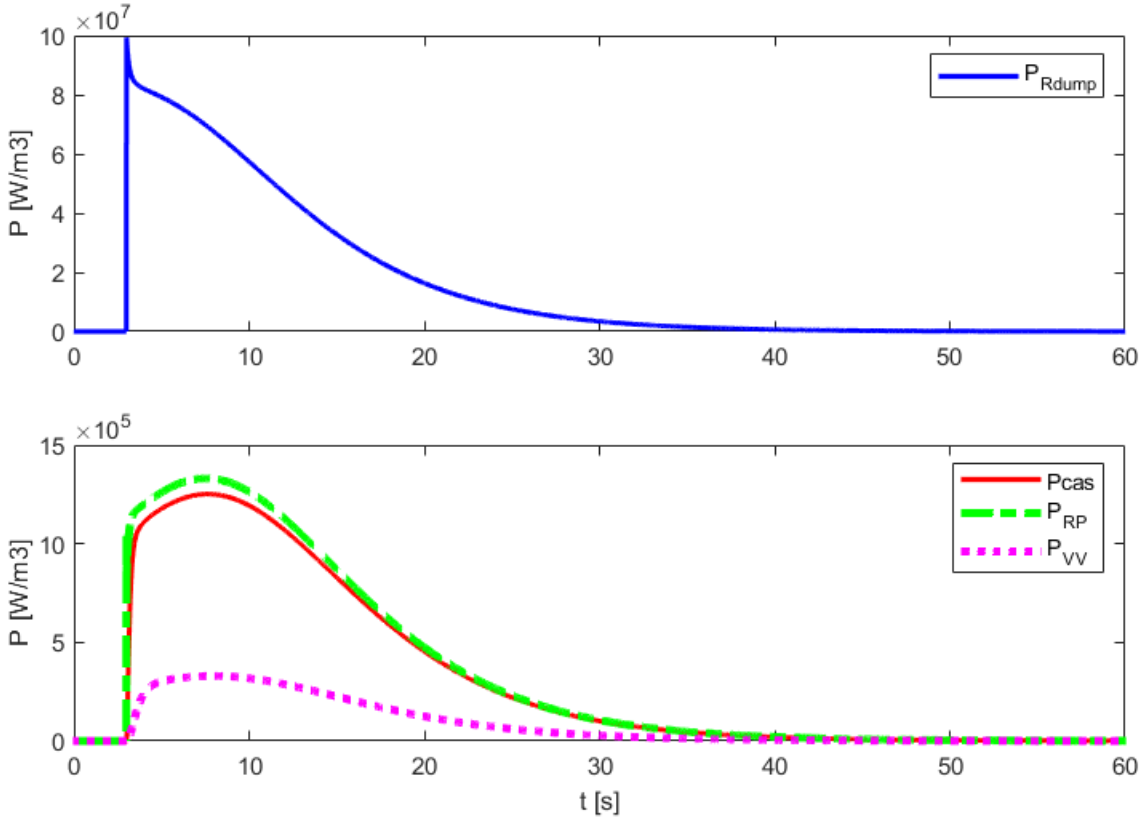
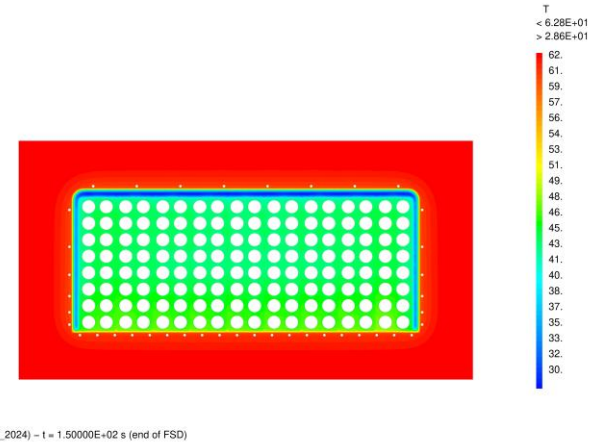
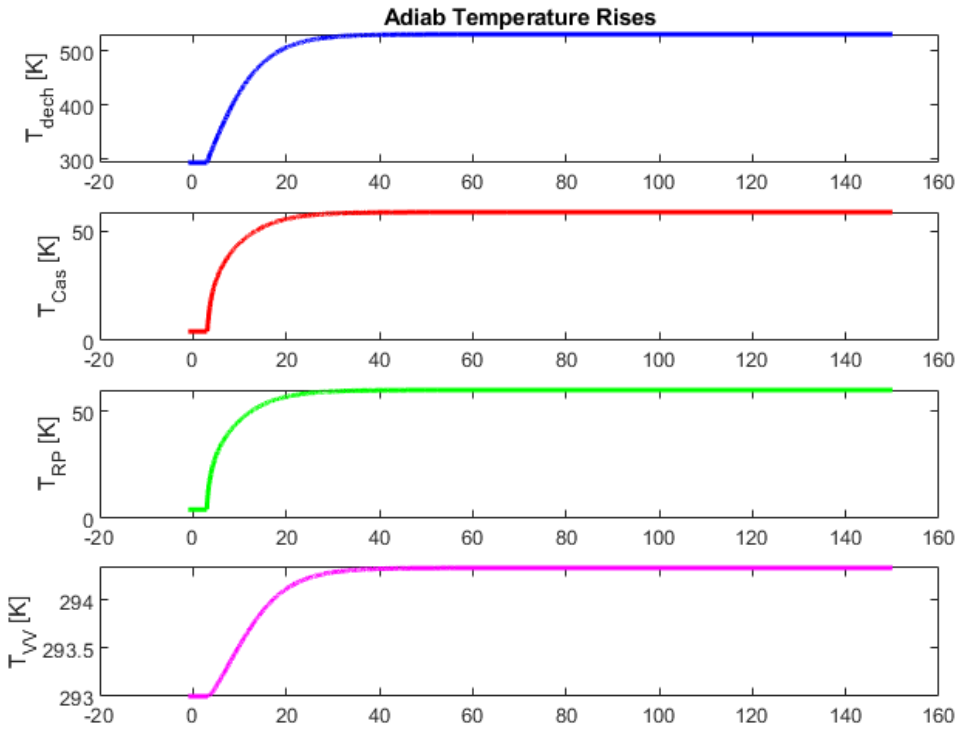
Induced currents in all elements are computed, and magnetic energy extraction can be computed.







2025 CEA TS
Electromagnetic analysis

FSD of TF magnet and induced currents

Power deposition is found and can be given to Thermohydraulic model.