Electromagnetic modelling of DTT scenarios and control

A. Castaldo

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Outline

- Education and training

- Activities carried out in 2023:

    - Definition of plasma electromagnetic scenarios and weak coupling with transport code ASTRA for DTT (scenarios A, C and E);
    - Disruption simulations for DTT;
    - Sweeping control;
    - Creation of IMAS structures for DTT;

- Foreseen activities for 2024;

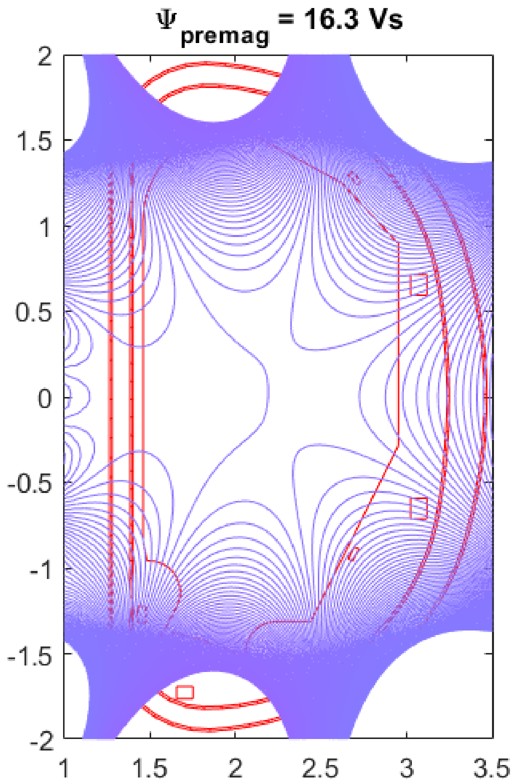
    - Definition of B-D scenarios and XD and NT for DTT;
    - Proposal for collaboration with WEST team;
    - Kinetic control for DTT;

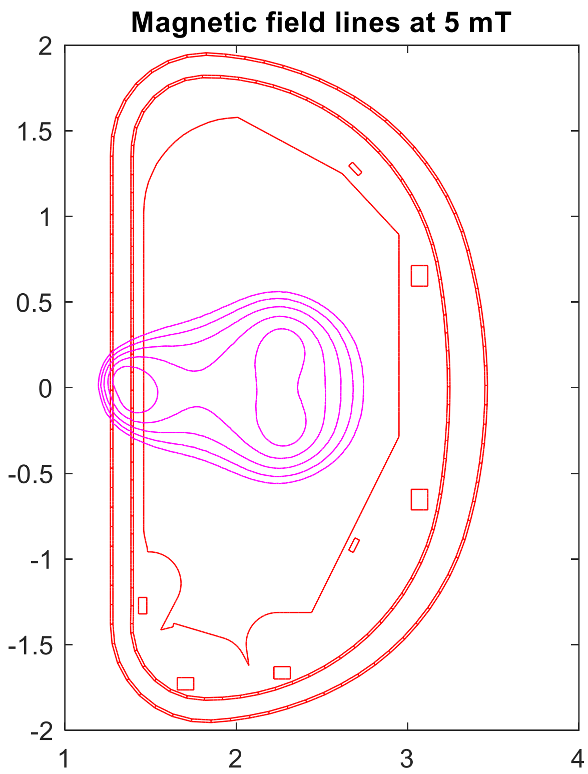
Education and training

- B.Sc and M.Sc in Management Engineering (Energy address) from University of Naples ‘Parthenope’;
- PhD student (XXXI° cycle) of Joint European Doctorate in Fusion Science and Engineering (University of Padova, University of Naples ‘Federico II’, ENEA, Max Planck Institute for plasma physics);
- Employee of CREATE Consortium and L.T. Calcoli;
- Researcher at ENEA (TD) research center in Frascati (from 01/06/2022 to 01/06/2023);
- Currently researcher at ENEA (TI) research center in Frascati;

DTT plasma scenarios (I)

- In 2023 plasma scenarios A, C and E have been released and uploaded on Alfresco Alfresco » Document Library (enea.it);
- The starting point for the definition of a scenario is the evaluation of the premagnetization phase;

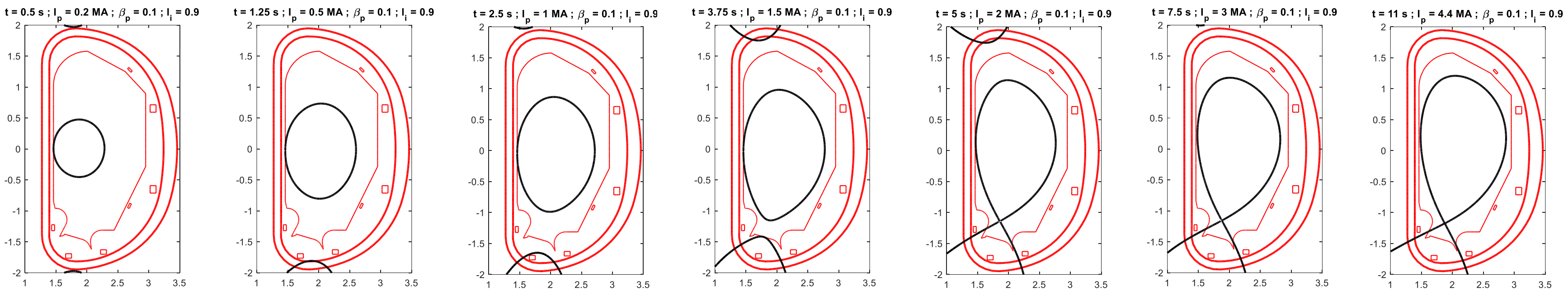




DTT plasma scenarios (II)

A preliminary definition of the ramp-up is realized starting from:

- Simplified sequence of the plasma shapes



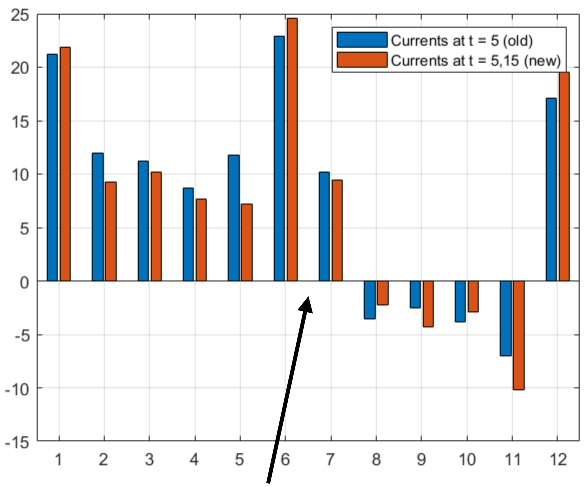
- Simplified plasma current profiles (Bell shape profiles)

  - Total plasma current I_p
  - Poloidal beta $\beta_{pol} = W_p / W_m$
  - Internal inductance $l_i = 4W_m / (\mu_0 R_0 I_p^2)$

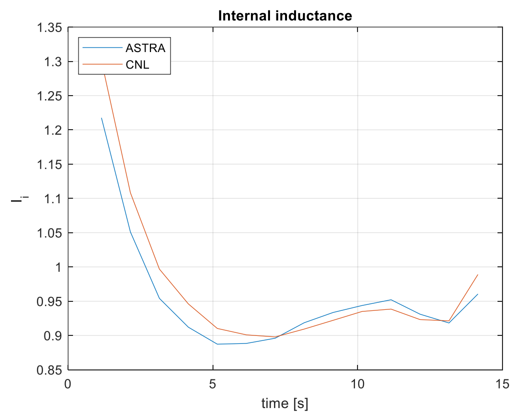
- Simplified assumption of the plasma boundary flux consumption (Ejima approach): $\Psi(t) = 0{,}5\mu_0 R_0 l_i I_p + C_{Ejima}\mu_0 R_0 I_p$

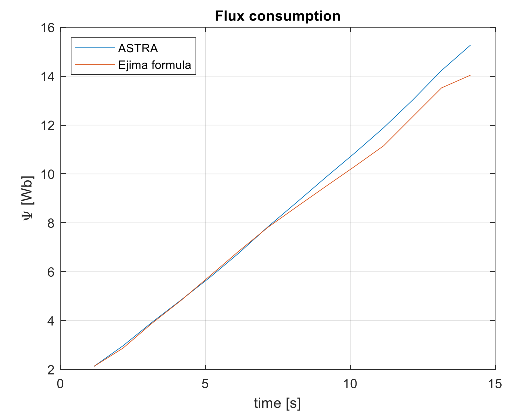
DTT plasma scenarios (III)

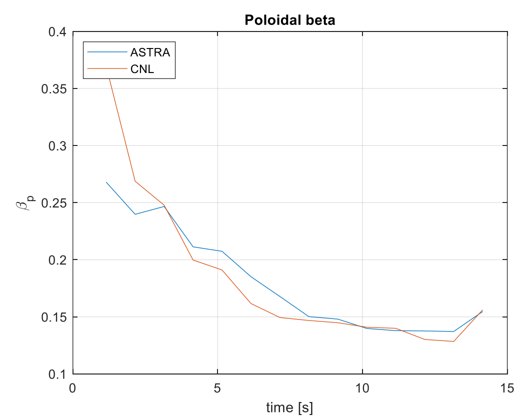
- In order to validate the proposed ramp-up, transport simulations performed with JINTRAC have been carried out;
- Since JINTRAC offers as outputs poloidal current function (f), pressure (p) and their derivatives, these quantities can be used as inputs of the e.m. code CREATE-NL+;



A tuning of CS/PF currents turns out to be necessary in order to fit plasma shape



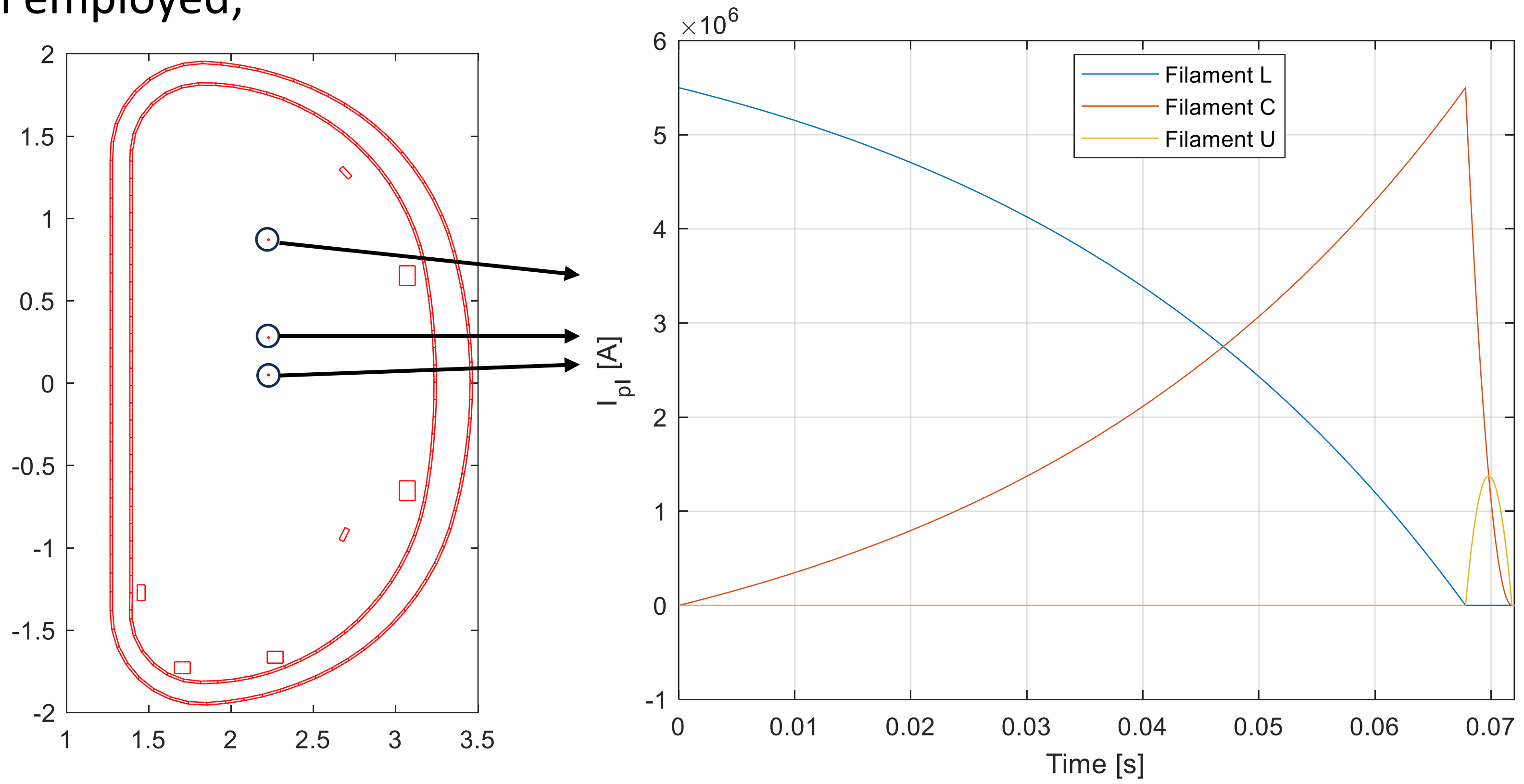




N. Bonanomi et all, ‘Time-dependent full-radius DTT scenarios prediction with reduced transport models’, TBD

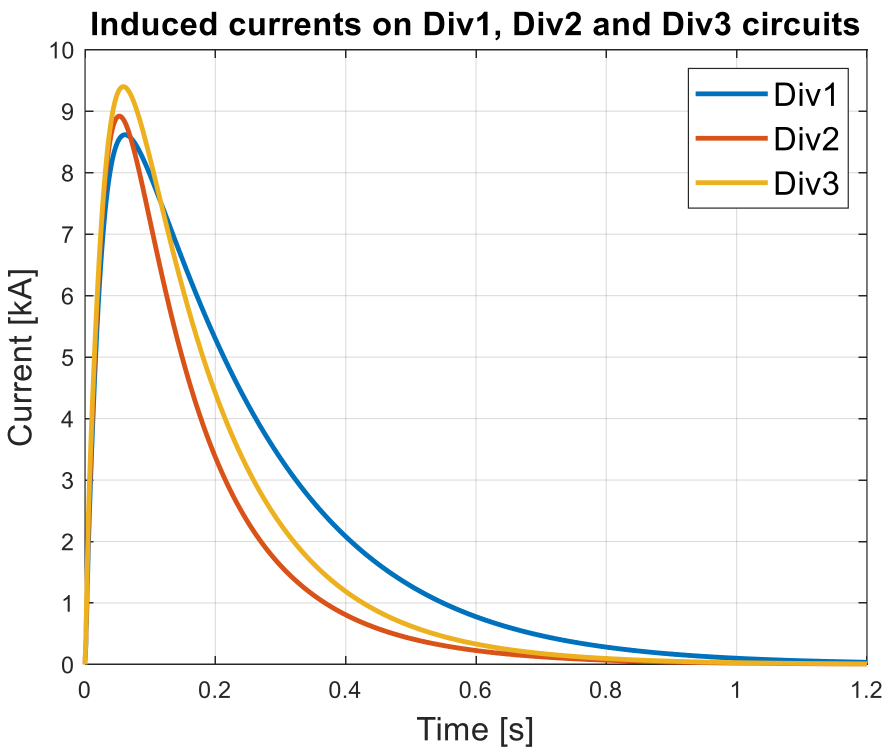
Disruption analysis for DTT in-vessel coils (I)

- Disruptive events can be very dangerous for the components of a tokamak machine, in particular for the elements closer to plasma column such as in-vessel coils;
- In order to simulate a disruption in DTT a simplified 3 filaments model has been employed;



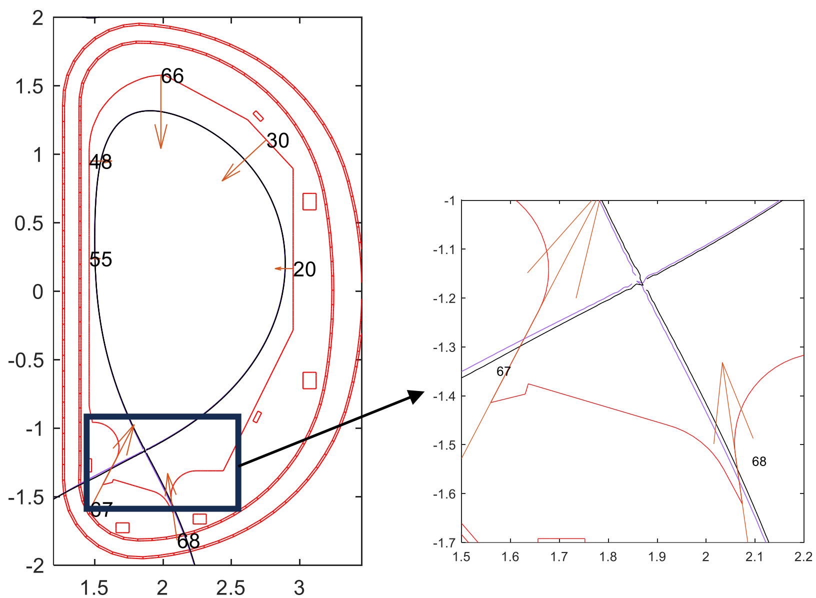
Disruption analysis for DTT in-vessel coils (II)

- In order to protect in-vessel coils during disruptions, additional inductances and resistances can be placed to reduce the current peaks during disruptions;
- The results obtained by linear simulation have been validated recently by non-linear simulations performed with CREATE-NL+ code;



Sweeping control for DTT (I)

- Since one of the main objective of DTT is to study different solutions for the power exhaust problem, a set of dedicated coils has been placed in the divertor region;
- These coils can be used for different purposes such as: assisting X-point formation, local control of flux/magnetic field in the divertor region, implementation of advanced control techniques such as strike-point sweeping;



Shape Gaps: 20, 30, 48, 55, 66

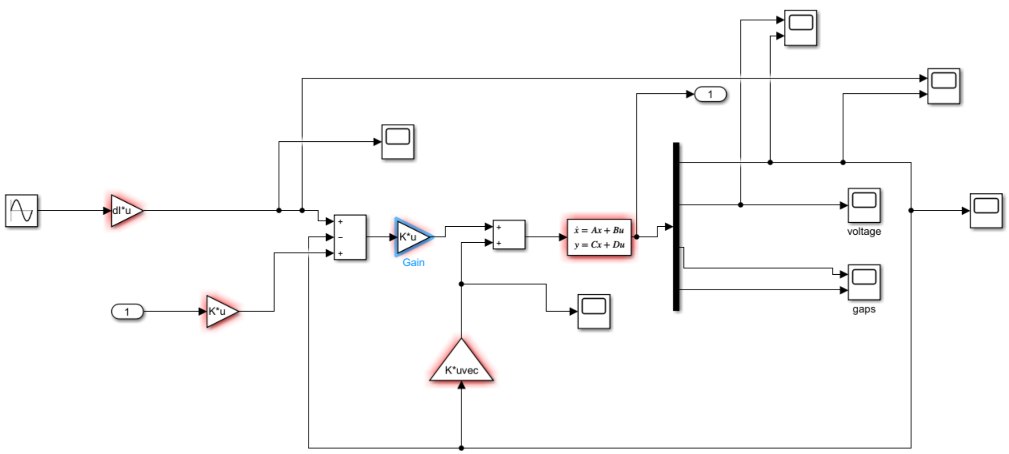
Sweeping Gaps: 67,68

ΔI_{sweep}^{eq} able to decouple sweeping of plasma legs and movement of plasma shape

Sweeping control for DTT (II)

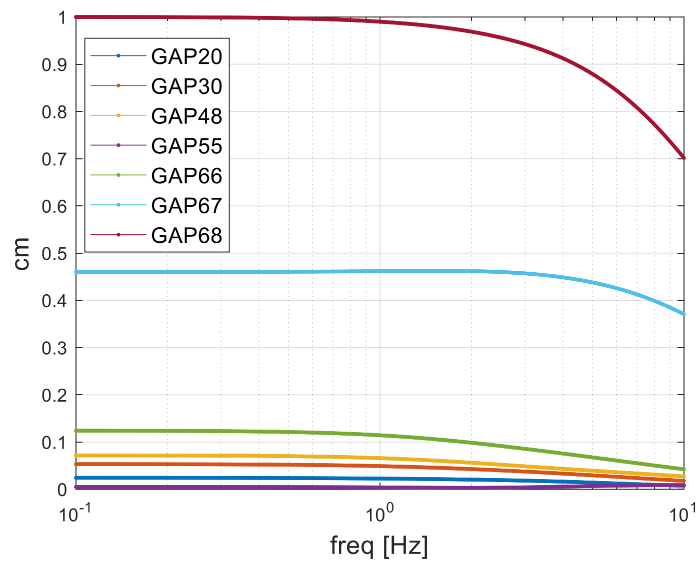
- Once computed ΔI_{sweep}^{eq} in order to implement legs sweeping the current control law to impose is $I_{sweep}(t) = \Delta I_{sweep}^{eq} \sin(\bar{\omega} t)$ where $\bar{\omega}$ is the sweeping frequency;
- In order to obrain the desired current dynamics since divertor coils are voltage driven the following voltage control law can be imposed (*):

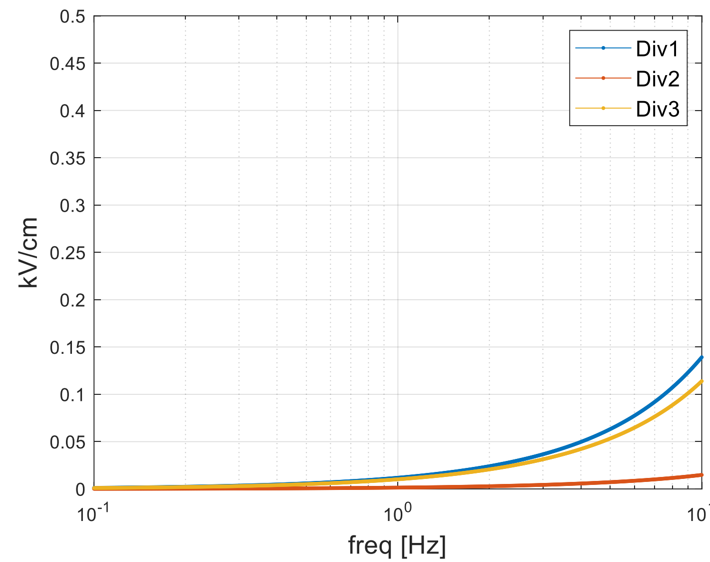
$$V_a(t) = \frac{L}{\tau} \Delta I_{sweep}^{eq} \tilde{V}(t) - \frac{L}{\tau} I_a(t) + R I_a(t)$$

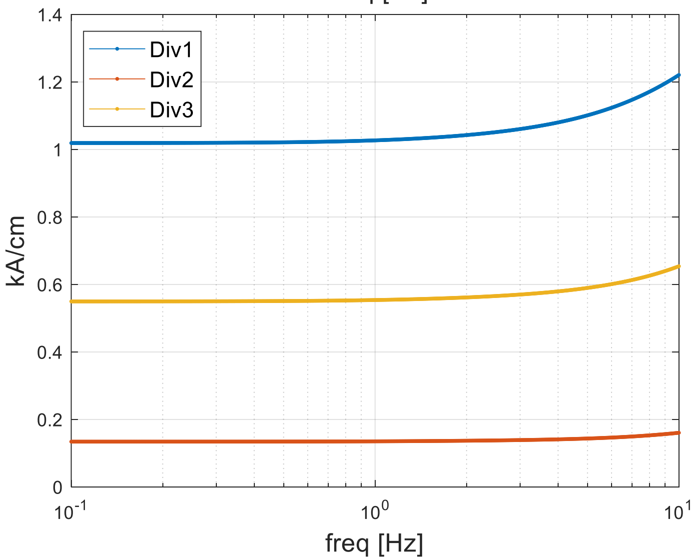


(*) – R. Ambrosino et all, 'Sweeping control perfomance on DEMO', Fusion Engineering and Design, Volume 171, October 2021

Sweeping control for DTT (III)

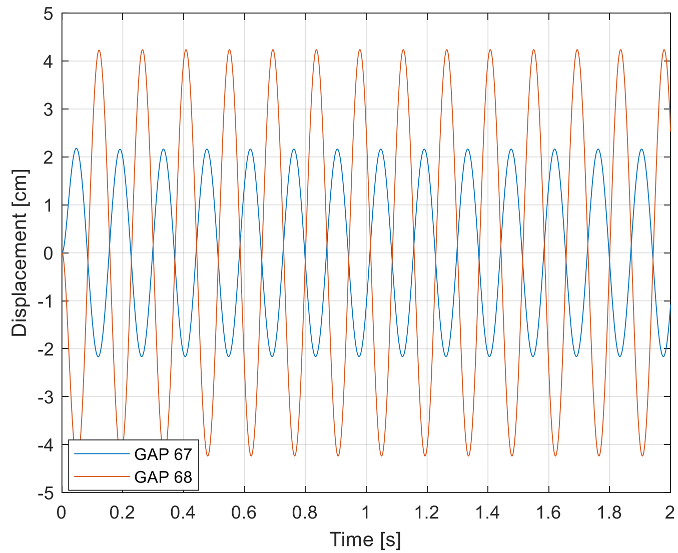


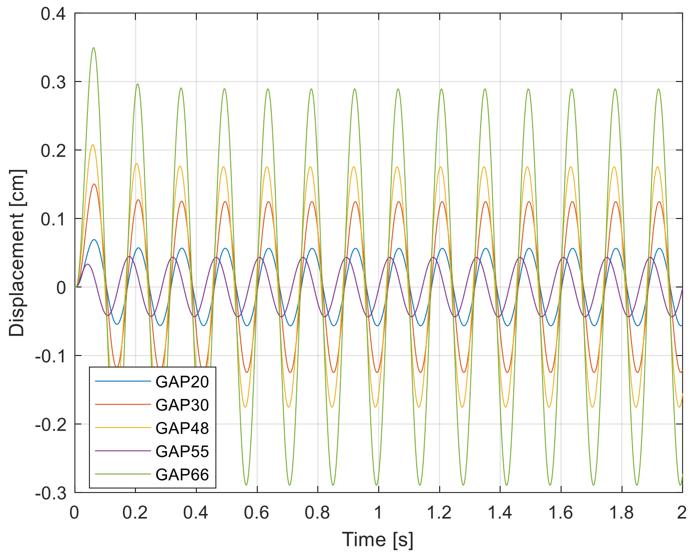


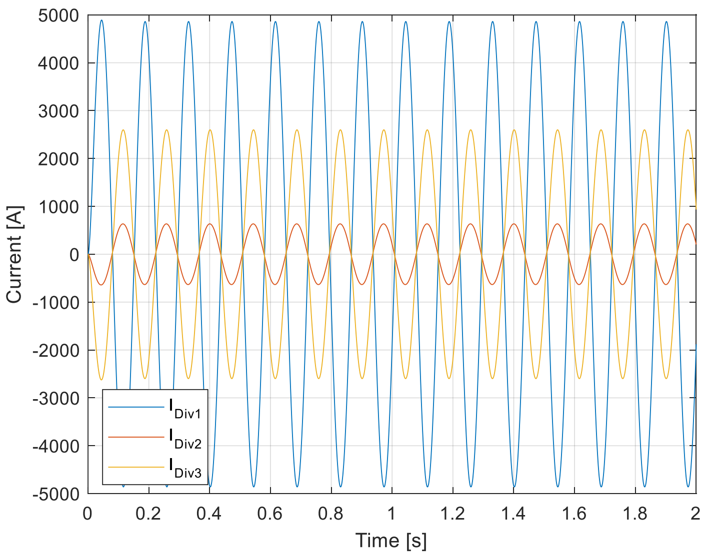


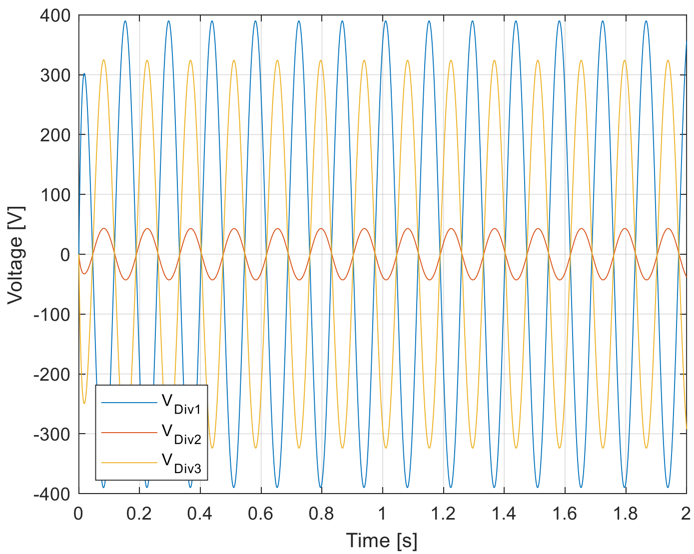
- Good decoupling between sweeping gaps and shape gaps in the frequency range $[1 - 10]$ Hz;
- According to voltage limit a sweeping amplitude of ± 4 cm at 7 Hz can ben imposed on the outer target and ± 2 cm on inner target;

Sweeping control for DTT (IV)









IMAS for DTT

- The Integrated Modelling & Analysis Suite (IMAS) is the collection of software that will be used for all physics modelling and analysis. It will represent the standard for ITER;
- The outputs from 2D FEM CREATE-NL+ code can be used (eventually postprocessed) in order to fill in a sub-set of IMAS fields;

IMAS Data Model (3.34.0)

Heating systems | Diagnostics

amns_data	disruption	iron_core	reflectometer_profile
barometry	distribution_sources	langmuir_probes	refractometer
bolometer	distributions	lh_antennas	sawteeth
bremsstrahlung_visible	divertors	magnetics	soft_x_rays
calorimetry	ec_launchers	mhd	spectrometer_mass
camera_ir	ece	mhd_linear	spectrometer_uv
camera_visible	edge_profiles	mse	spectrometer_visible
charge_exchange	edge_sources	nbi	spectrometer_x_ray_crystal
coils_non_axisymmetric	edge_transport	neutron_diagnostic	summary
controllers	em_coupling	ntms	temporary
core_instant_changes	equilibrium	pellets	thomson_scattering
core_profiles	gas_injection	pf_active	tf
core_sources	gas_pumping	pf_passive	transport_solver_numerics
core_transport	gyrokinetics	polarimeter	turbulence
cyrostat	hard_x_rays	pulse_schedule	wall
dataset_description	ic_antennas	radiation	waves
dataset_fair	interferometer	real_time_data	workflow

2024 foreseen activities

- For 2024 the activities foreseen are the following:

  - Revision of A, C and E scenarios on the new CS version (v16) with two layers and coupling with ASTRA for all the scenarios phases;
  - Definition of B and D scenarios on the latest version of the machine design;
  - Study of alternative configurations (XD and SN-NT) with the definition of proper electromagnetic scenarios compatible with machine constraints;
  - Further disruption analysis to be defined in order to study the behavior of the 2 layer CS;
  - Definition of a complete DTT scenario on IMAS workflow;
  - Start of the activities on kinetic control (definition of the model, controllers tuning, identification of the available diagnostics);

Proposal for WEST activites

- Electromagnetic analysis of the WEST tokamak:
  - Definition of the 2D mesh, development of linearized models of the device;
  - Testing of the E.M. models developed by simulation of dry-runs;
- Validation of models with plasma developed by comparing plasma shape and physical quantities obtained with reconstruction codes employed on WEST;
- Analysis and optimization of ramp-up, flat-top and ramp-down phases;
- All the analysis will be carried out using 2D FEM solver CREATE-NL+ code and CREATE-L code for linearized plasma response;