Plasma control tools development and training

31 May 2024

G. De Tommasi
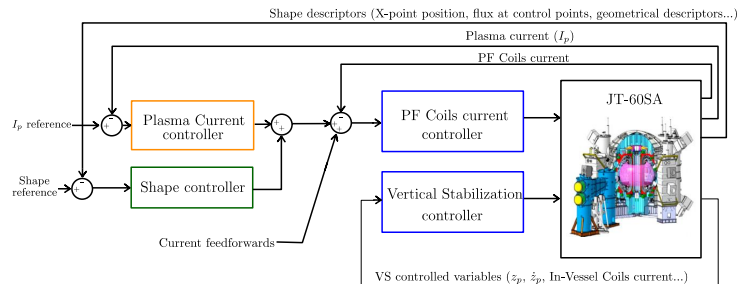on behalf of the CREATE Team

Outline

- EU tools available for plasma control
  - Current status
  - Recent studies → **architecture with explicit VS system to operate with elongated plasma in absence of in-vessel coils**

- Ongoing activities

- Next activities & interaction with the Experimental Team

EU tools for plasma control

- A set of *control-oriented* tools in the Matlab/Simulink environment are available since **2017-2018** using Matlab and Simulink

- The tools enable…
  - Model-based design of plasma magnetic control algorithms (VS, Ip control, position and shape control)
  - Fast simulation (in the Simulink environment) to assess controller performance and tune gains during operation (QST does not have such a tool so far…)

- …and have been used to
  - Propose a possible architectures for plasma magnetic control at JT-60SA (recently also for IC/OP1, to accomplish VS in absence of in-vessel coils)
  - Assess the performance of the magnetic control (example, check feasibility of ELM pacing VS kicks)
  - Perform code benchmarking (QST codes run in closed-loop with CREATE linear models)

Shape descriptors (X-point position, flux at control points, geometrical descriptors...)
Plasma current (I_p)
PF Coils current
I_p reference — Plasma Current controller
Shape reference — Shape controller
Current feedforwards
PF Coils current controller
JT-60SA
Vertical Stabilization controller
VS controlled variables (z_p, $\dot{z}_p$, In-Vessel Coils current...)

Architecture for equilibrium control during IC

- Equilibrium control during IC includes (see also *Inoue et al.*, Nuclear Fusion 2021)
  - two outer controllers : I_p **control** and **(isoflux) plasma boundary control**
  - one inner **CS/EF current controller**
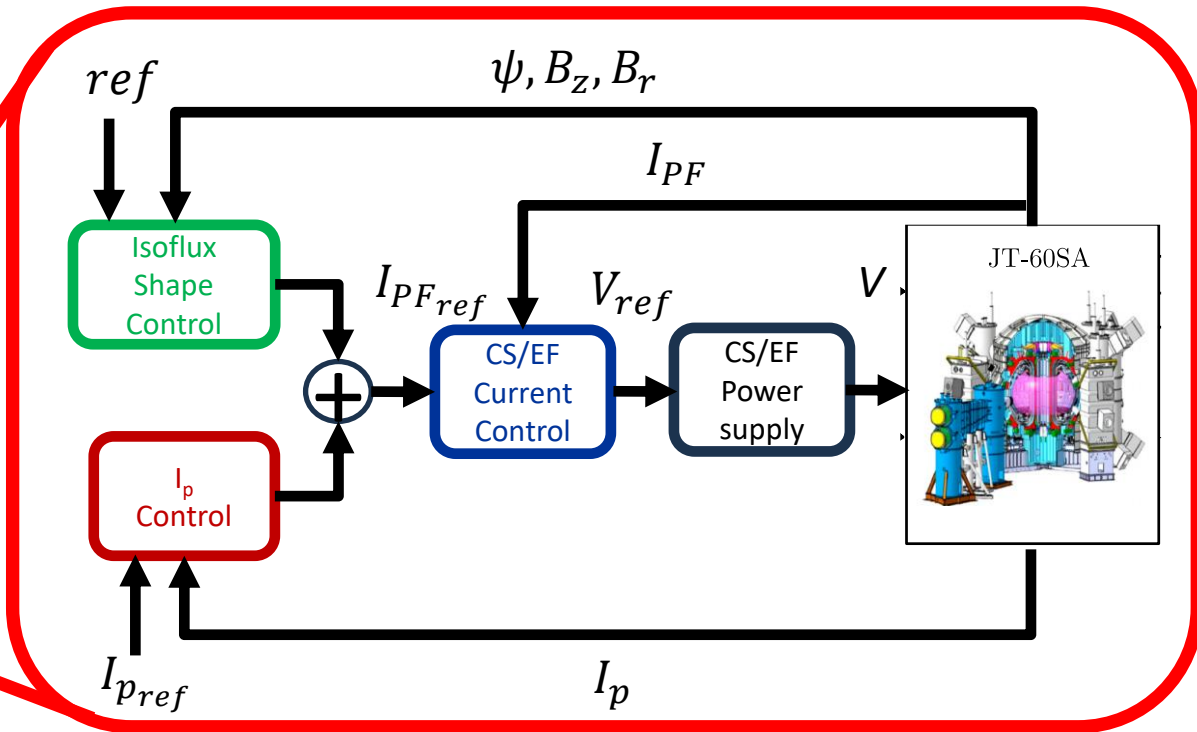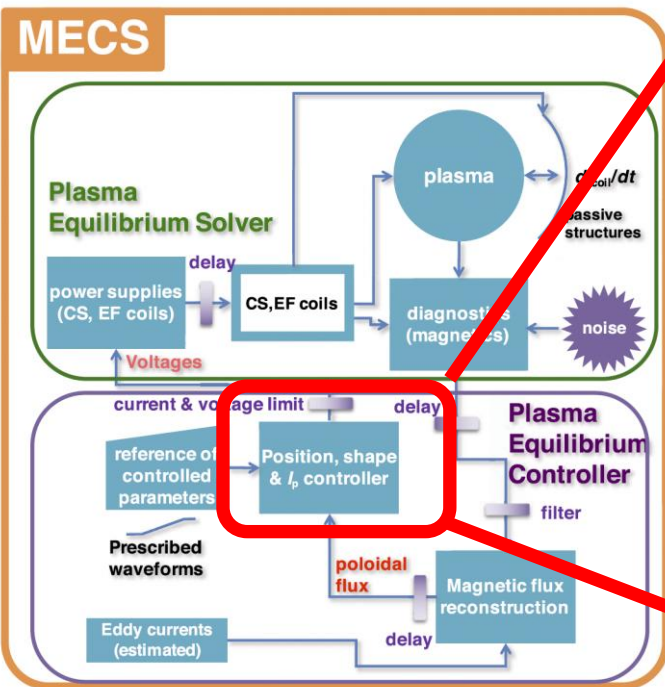
Benefit of explicit VS in absence of in-vessel coils

- Slightly elongated and stable plasma equilibria are *de facto* unstable due to the presence the **inner current controller**, that causes a loss of the passive stabilization effect of the CS/EF coils, which is not negligible in absence of passive stablizers and in-vessel coils

	Growth rates comparison		
	γ (s^{-1})	γ_{NC} (s^{-1})	γ_R (s^{-1})
Eq#1	0.36	7.00	6.83
Eq#2	1.13	7.81	7.62
Eq#3	4.02	10.01	9.78
Eq#4	7.64	13.48	13.20
Eq#5	Stable	2.33	2.27

γ - linear model growth rate

γ_{NC} - growth rate with *ideal* PFC current control

γ_R - growth rate obtained by including the effect of the considered PFC current control


Plasma equilibria shapes

- As a consequence **(confirmed during IC/OP1)**:
  - stable equilibria become vertically unstable
  - slighly unstable equilibria the growth rate increases even more
- **Investigate the possibility of including an *explicit* VS system**
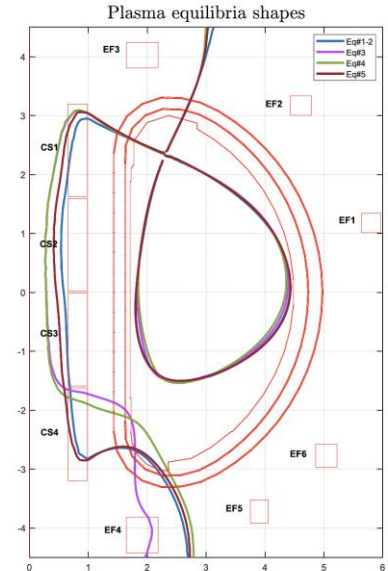
Include a VS system in the reference architecture

- **VS system** exploits a weighted combination of EF3 and EF4 currents
- I_p control exploits a transformer current projected in the null subspace of the EF3/EF4 combination used by the VS
- **isoflux (with an XSC-like approach)** control exploits the remaining CS/EF coils adoptin a similar approach as for I_p
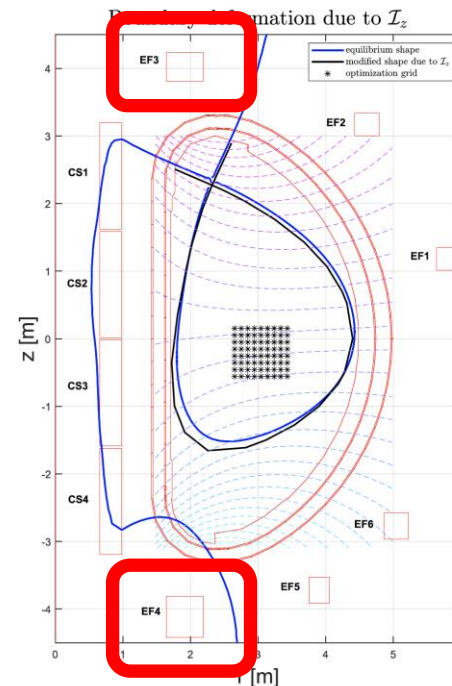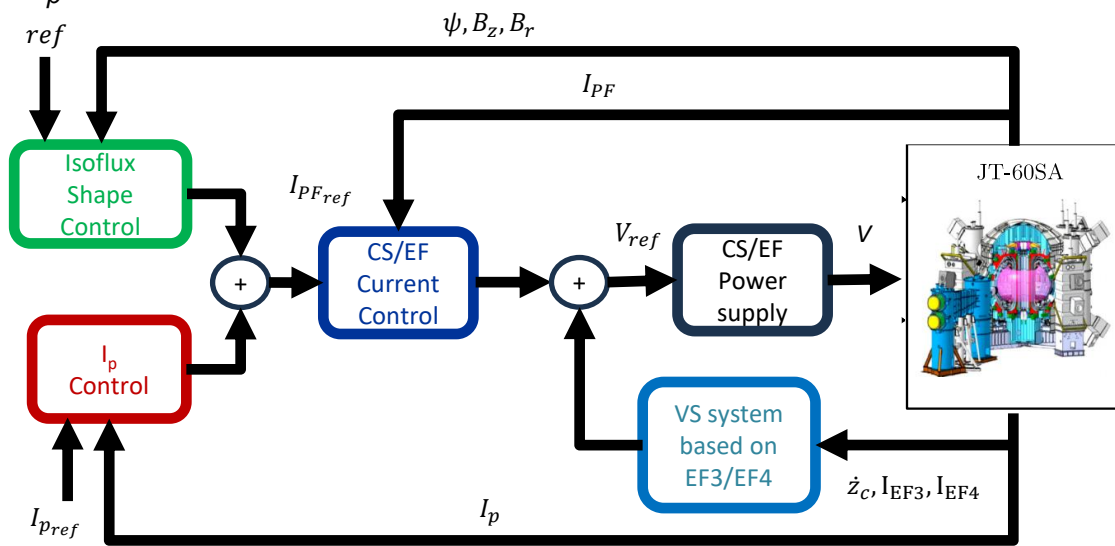
G. De Tommasi *et al.*, **Nuclear Fusion**, 64(7), 2024

- Reconstruction of the plasma current

- Reconstruction of the plasma centroid position

- Reconstruction of the plasma boundary

- Reconstruction of poloidal beta

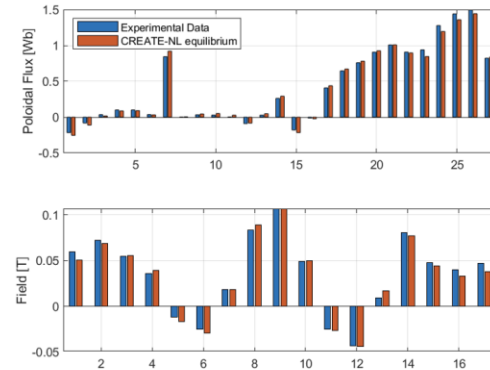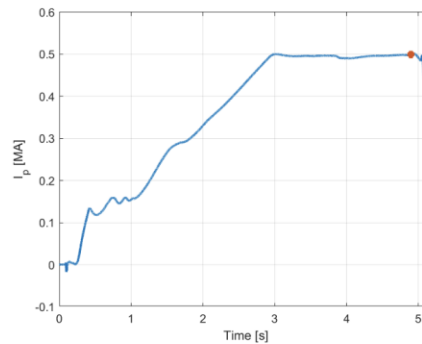→ *Proposal for a poster at SOFT 2024*

Ongoing activity – 1/2

- Generate a **database of CREATE-NL equilibria (snapshots) starting from a list IC/OP1 pulses**

Preliminary results presented in
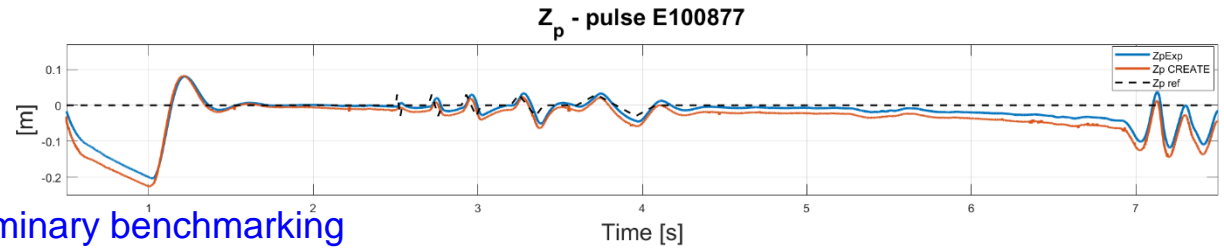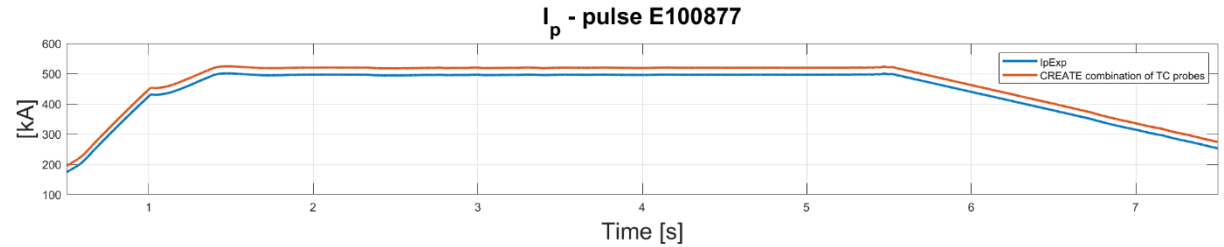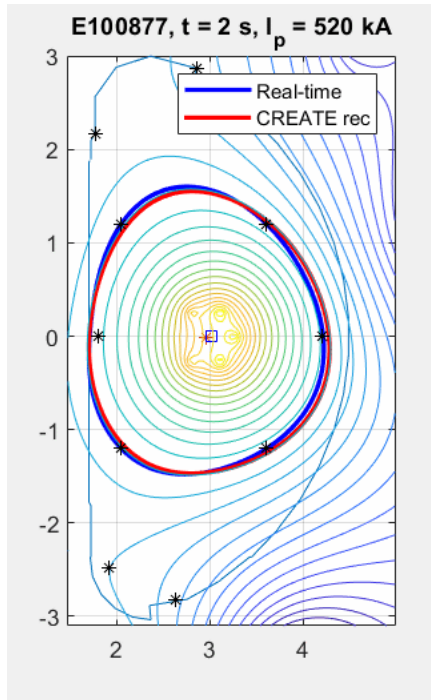Naka on 10 Nov 2023 at the PTM
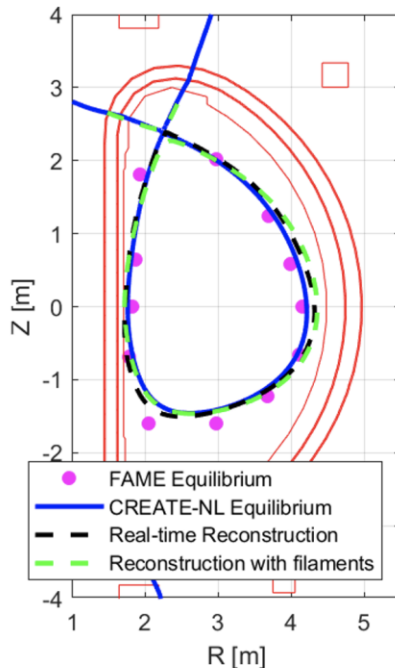
E100737 – t=4.9s

|	β_{pol}	li	$Growth\ rate\ [1/s]$
CREATE-NL Eq.	0.132	0.94	8.9

Ongoing – 2/2

- Preliminary deployment of the reconstruction algorithms adopted by ITER has been revised (plasma boundary reconstruction has been improved)

E100877, t = 2 s, I_p = 520 kA

Preliminary benchmarking performed during IC

I_p - pulse E100877

Z_p - pulse E100877

R_p - pulse E100877
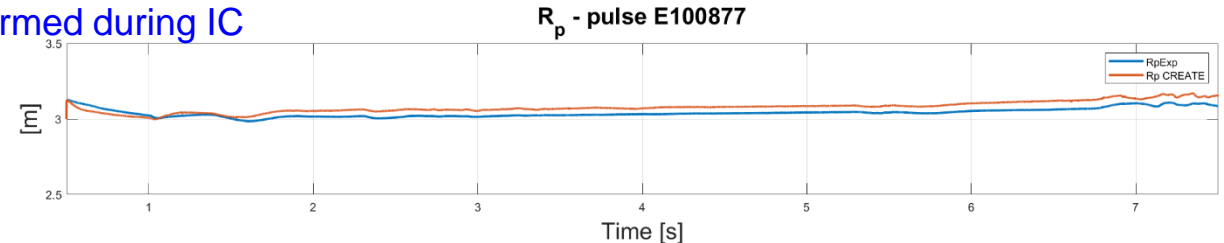
- The activity was delayed by late re-activation of Naka server account (Naka server has been practically not accessible since mid May 2024)

- Calibrated diamagnetic flux needed for poloidal beta estimation → details asked to QST (Urano & Miyata) → no answer yet → **how to proceed to interact with QST colleagues in a fruitful way? Experiment Team?**
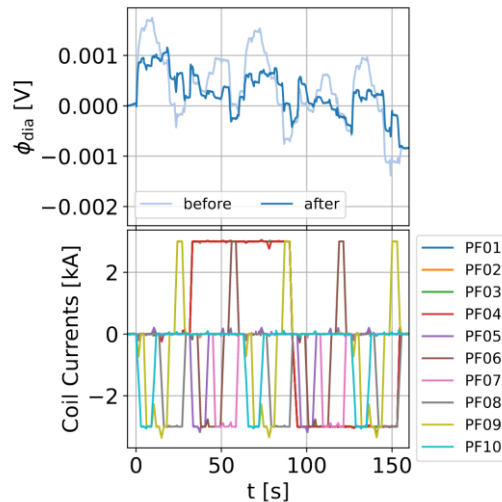
Diamagnetic Measurements in the Integrated Commissioning Phase of JT-60SA: The Role of Shafranov Integrals in Poloidal Beta and Internal Inductance Evaluation

S. Inoue[1], N. Oyama[1], M. Takechi[1], S. Tsuji-Iio[2], Y. Ohtani[1], R. Sano[1], S. Kojima[1], Y. Miyata[1], H. Yamazaki[1], T. Koabashi[1], T. Wakatsuki[1], H. Urano[1], M. Yoshida[1], and T. Suzuki[1]

[1] National Institutes for Quantum and Radiological Science and Technology, Naka, Ibaraki 311-0193, Japan
[2] Tokyo Institute of Technology, Ookayama, Tokyo 152-8550, Japan

E-mail: inoue.shizuo@qst.go.jp

April 2024

Proposed paper available on DMS

Next activities

- Gain expertise with QST tools (MECS, SELENE, …)

- Interface/benchmark EU control-oriented tools with QST ones
    - → POSSIBLE ACITIVITIES
        - → to validate proposed architecture for VS in absence of in-vessel coils to setup a procedure/interface between EU and QST in view of possible future contributions to plasma magnetic control for OP2/OP3

        - → to replicate/back engineering the QST control architecture in the Simulink environment to validate CREATE-NL model in closed loop with IC/OP1 experimental data

- **WPSA-OP and/or Experiment Team activity ??**