EUROfusion

Simulation of JT-60SA magnetic control and integration of CCS reconstruction code

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- **Reference Scenario, Control Points and Disturbances**
- **XSC-like approach for as *Isoflux* plasma shape controller**
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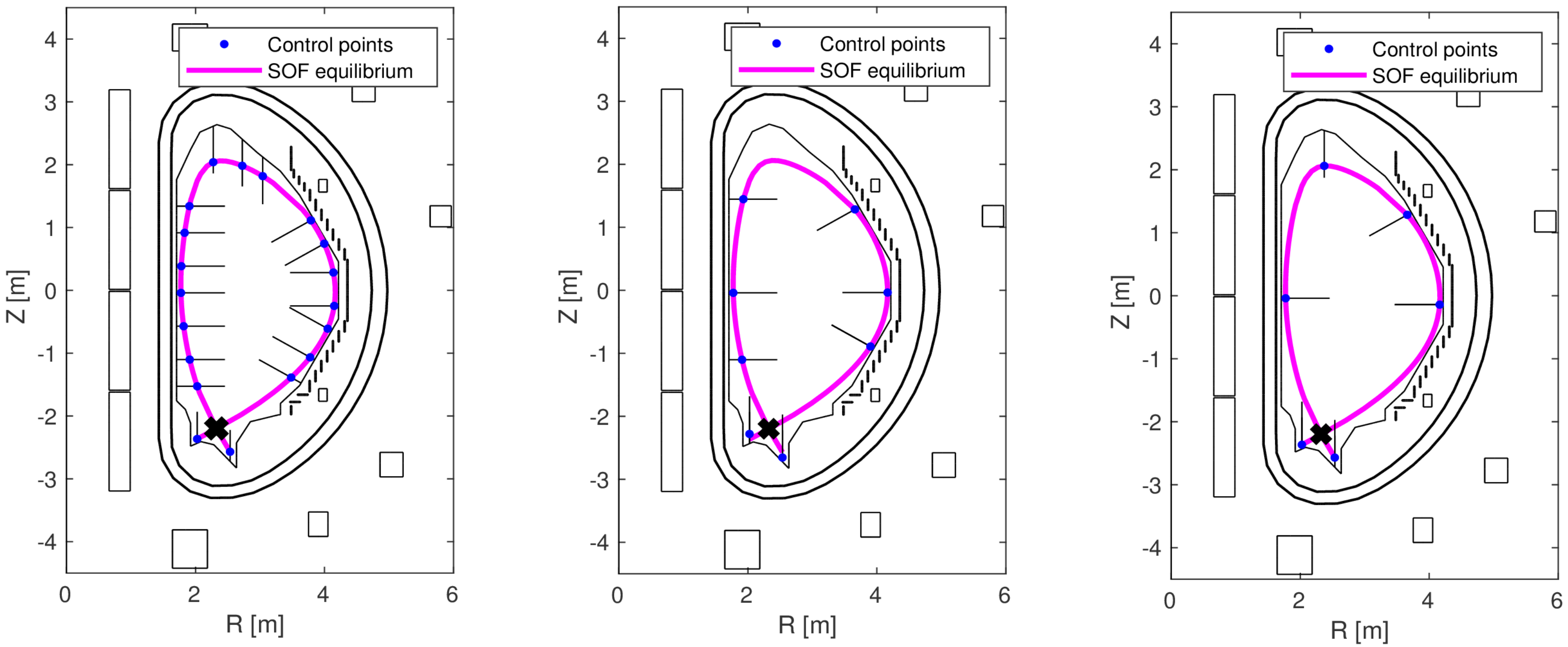
Integration of the CCS reconstruction code

The Cauchy Condition Surface (**CCS**) method reconstructs the plasma Last Closed Flux Surface (LCFS), the poloidal magnetic fluxes at a set of selected control points and the flux at the X-point.

- Code provided by the JT60-SA team
- Inputs: Measured Poloidal Field (PF) Coil currents, Plasma current (Ip) and measurements at the 45 field sensors and 34 flux sensors
- Outputs: Magnetic fluxes at the selected control points (maximum of 19) and flux at the X-point.

Reference Scenario and Control points

JT-60SA Scenario 2, *Ip* = 5.5 MA , Start Of Flat-top (SOF) t=18.66 [s]

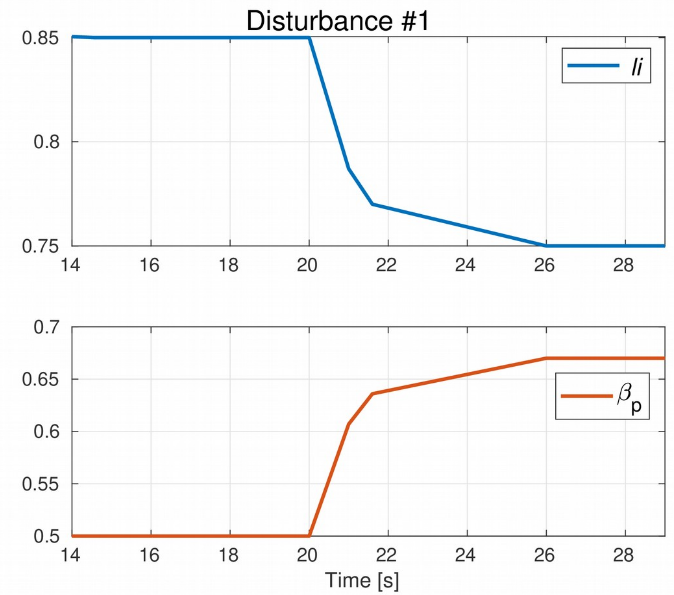


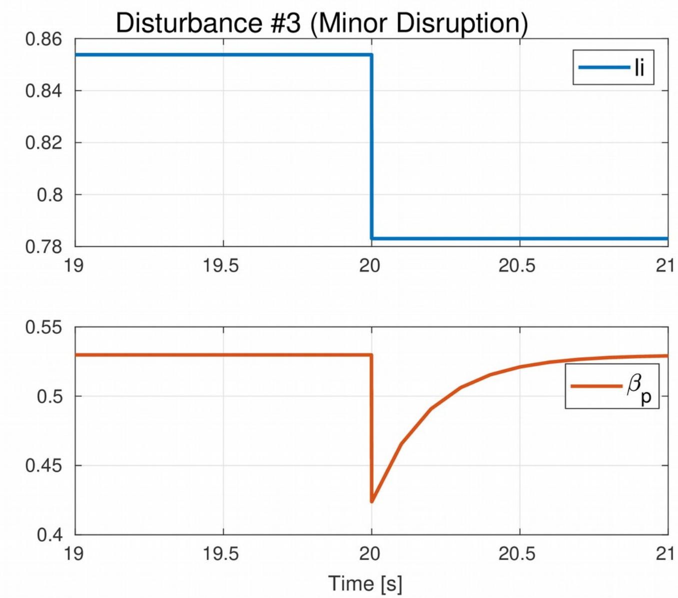
18 equally spaced control points + 2 strikes

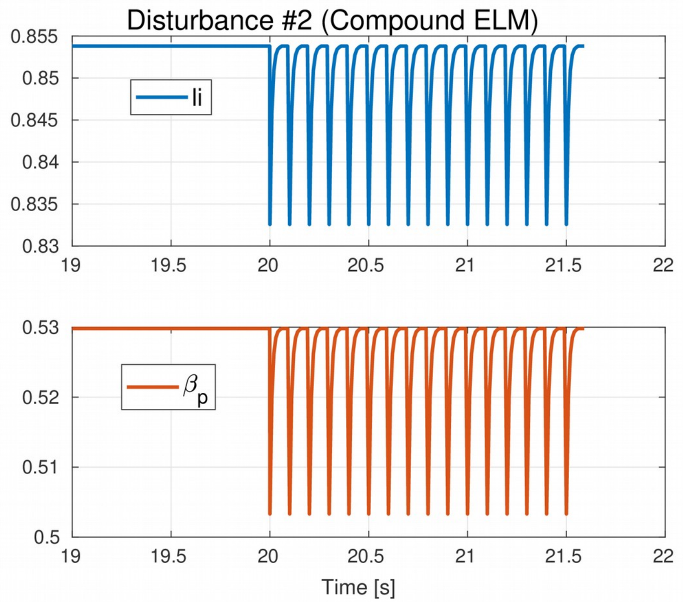
6 control points + 2 strikes (from *Miyata et al., PFR 2014*)

4 control points + 2 strikes (from *Miyata et al., PFR 2013*)

Disturbances







- Disturbance # 1 (*Urano et. al FED 2015)*
- Disturbance # 2 ,*Compound ELM (PID Technical report, p.34)*
- Disturbance # 3, *Minor Disruption(PID Technical report, p.34)*

Plasma shape control

- The proposed shape controller relies on the *XSC approach,* which was originally proposed for the JET tokamak (*Ariola and Pironti, IEEE CSM 2005*)

- **The XSC approach can be applied both to gap and isoflux control**

- Given a reference equilibrium, by adopting the correspondent plasma linear model, the **dynamic** of the variations of the n_Y shape descriptors (either flux differences or gaps) is given by

$$\delta Y(s) = C \cdot \frac{\delta I_{PF_{ref}}(s)}{1 + s\tau_{PF}}$$

It follows that the **static relationship** between the controlled variables and the PF currents is equal to

$$\delta Y(s) = C \cdot I_{PF_{ref}}(s) \qquad (1)$$

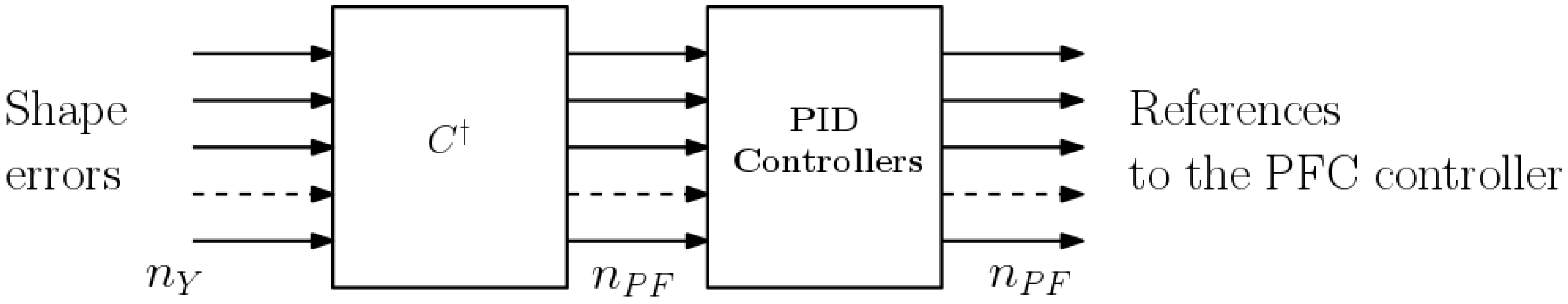
Plasma shape control

From (1) it follows that the PF currents needed to track the desired shape (in a **least-mean-square sense**) are given by

$$\delta I_{PF_{ref}} = C^{\dagger}\delta Y$$

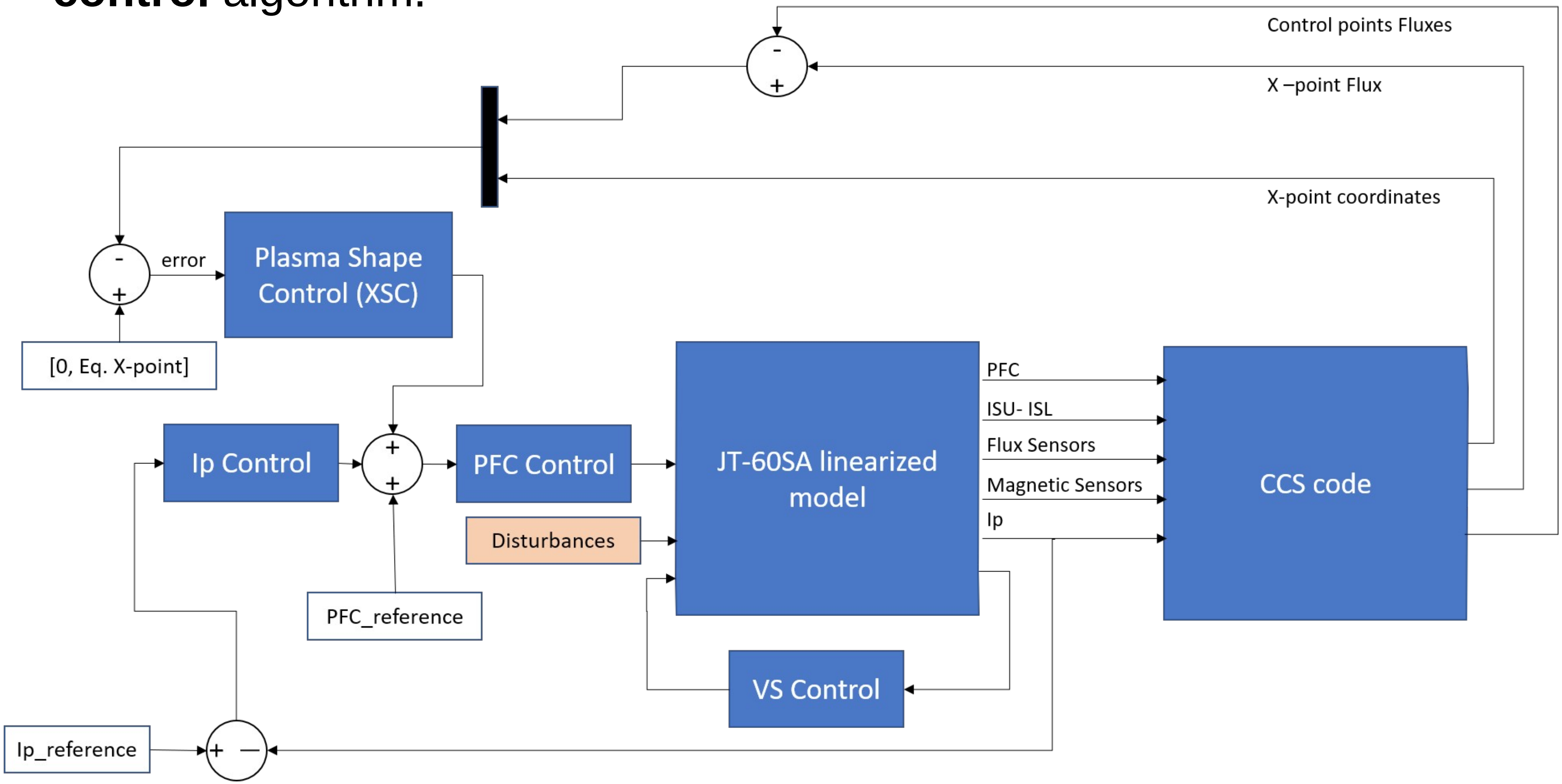
Where $C^{\dagger}$ the pseudo inverse of the *C* matrix, which can be computed using SVD

PIDs are added to improve the dynamic behavior of plasma shape control

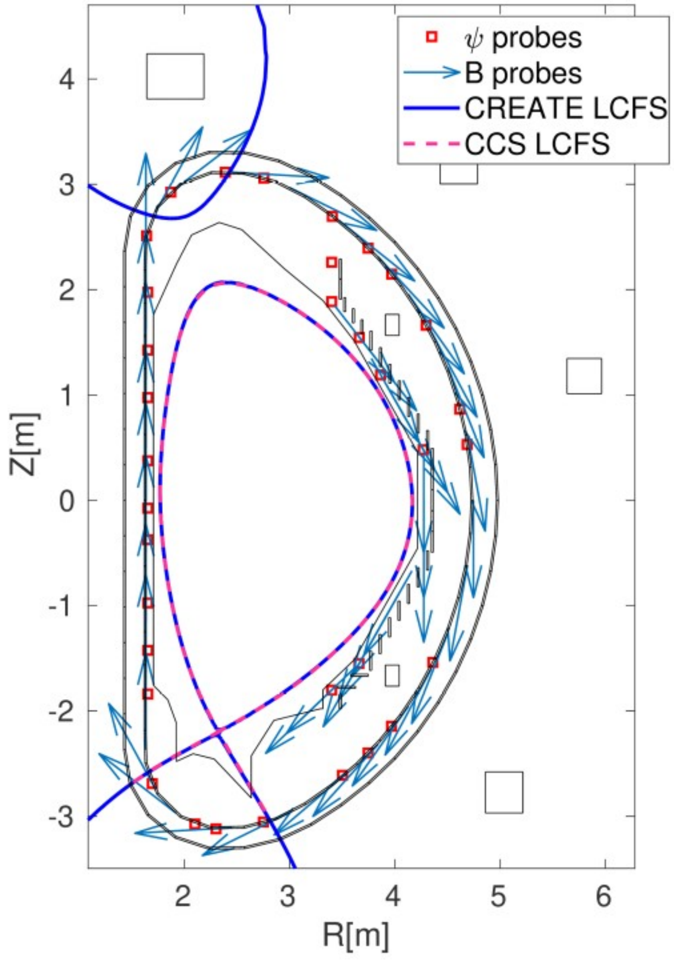


Integration of the CCS reconstruction code

The **fluxes** provided by the **CCS** reconstruction code at the selected control points are **fed back** to the eXtreme Shape Controller (**XSC**) in order to track the desired plasma shape by means of an **isoflux control** algorithm.

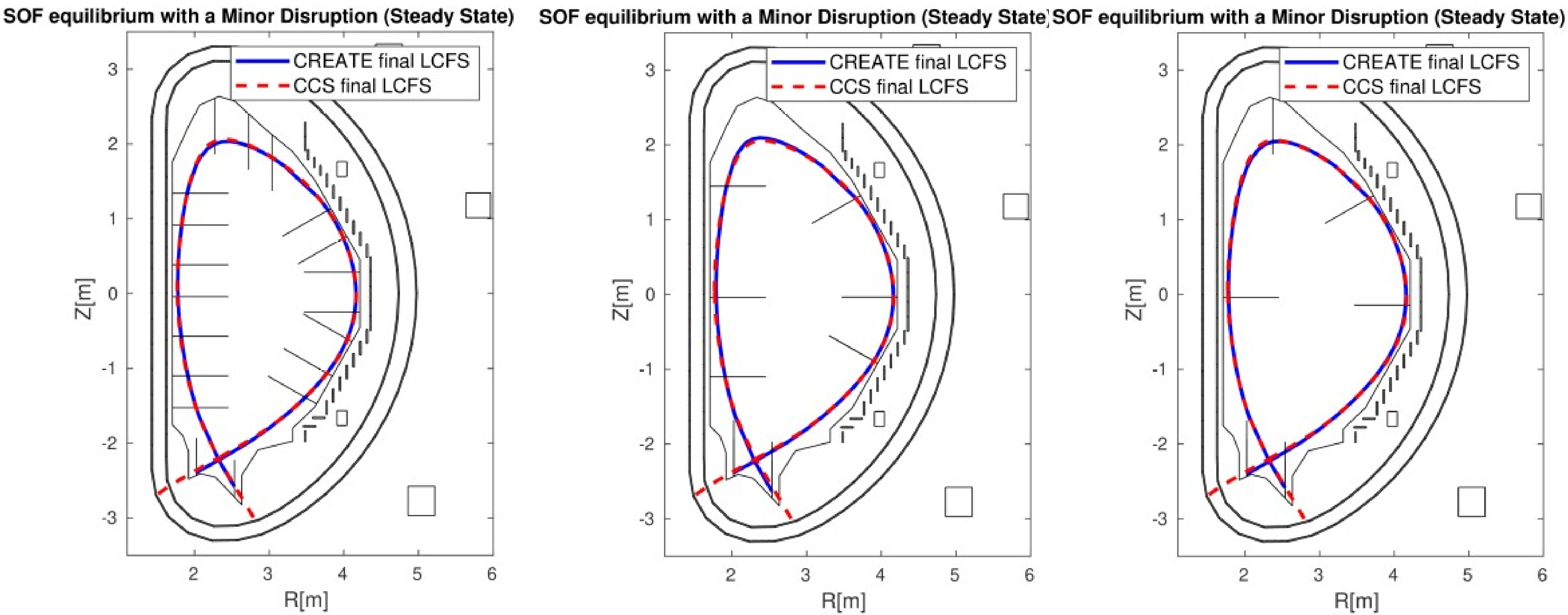


Simulation Results

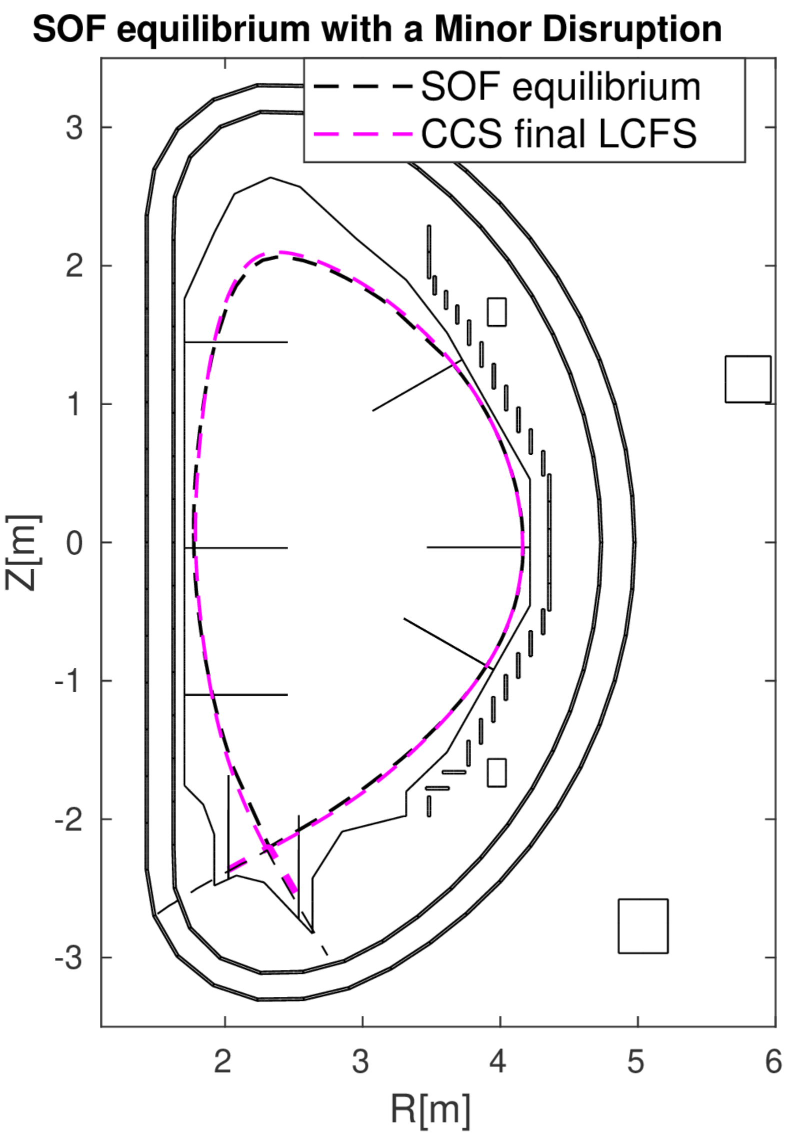


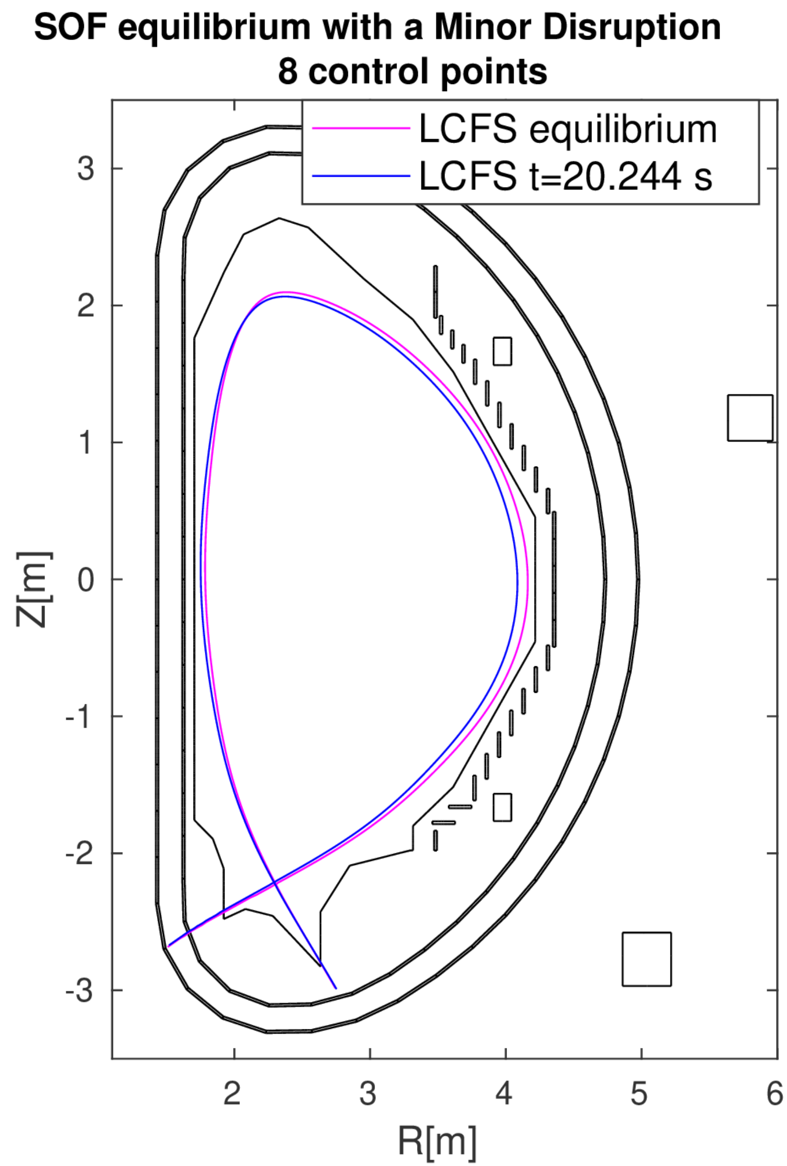
SOF equilibrium reconstructed from CREATE-NL modelling tool, CCS reconstruction code and locations of magnetic field and flux sensors.

Simulation Results – LCFS comparison

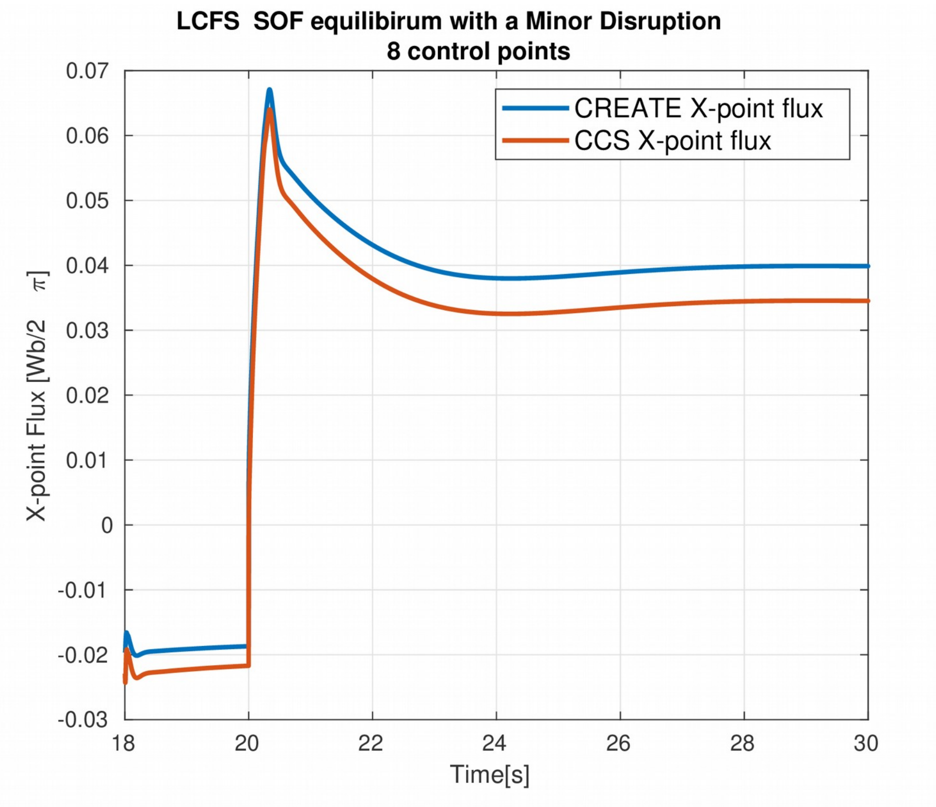


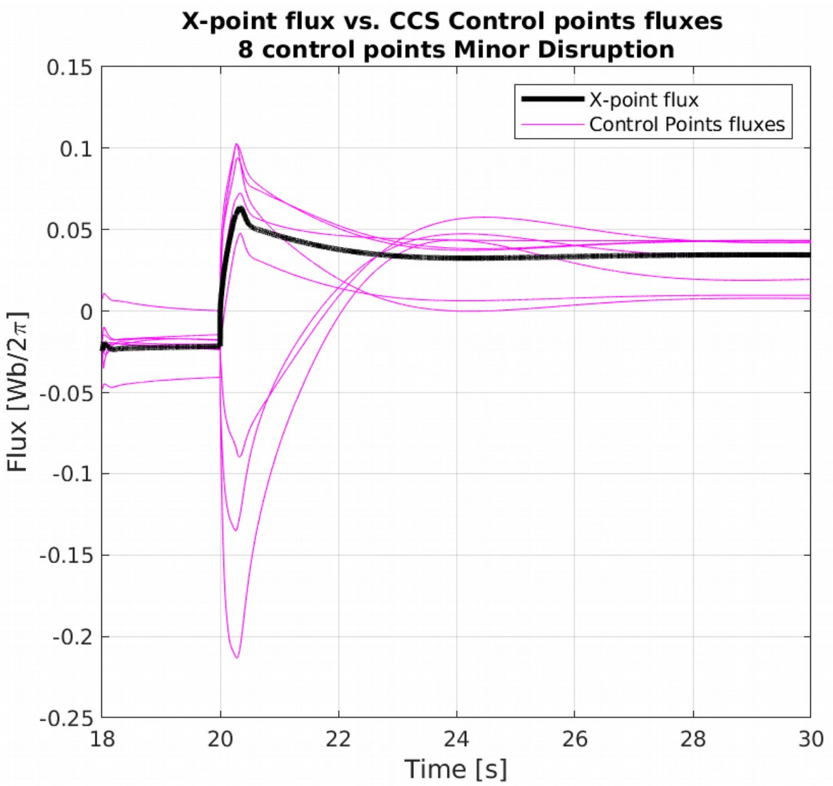
Isoflux Control Results



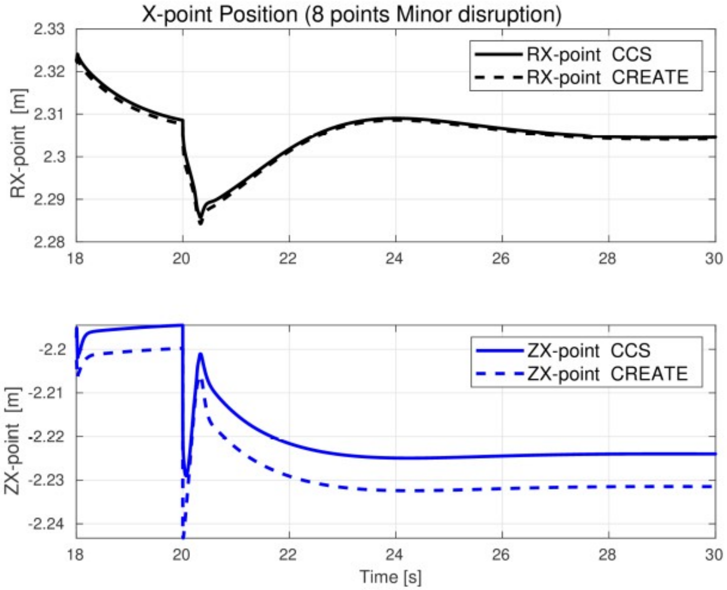


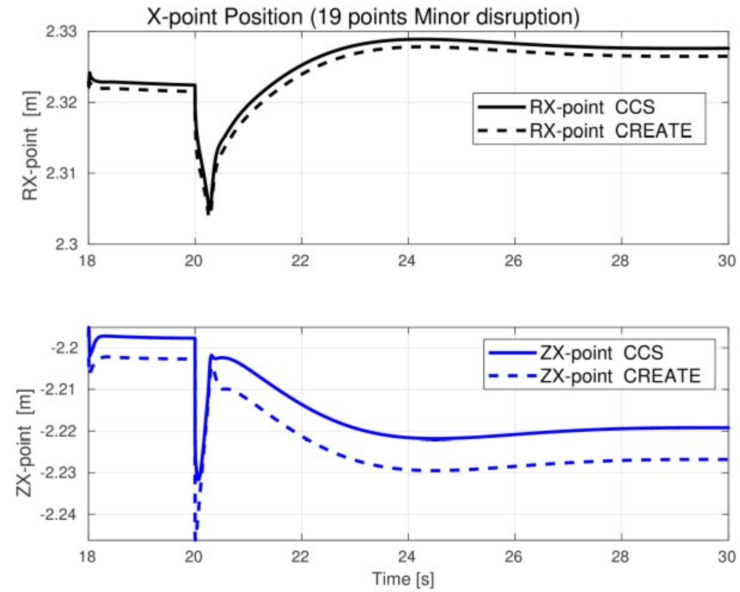
Simulation Results – LCFS flux

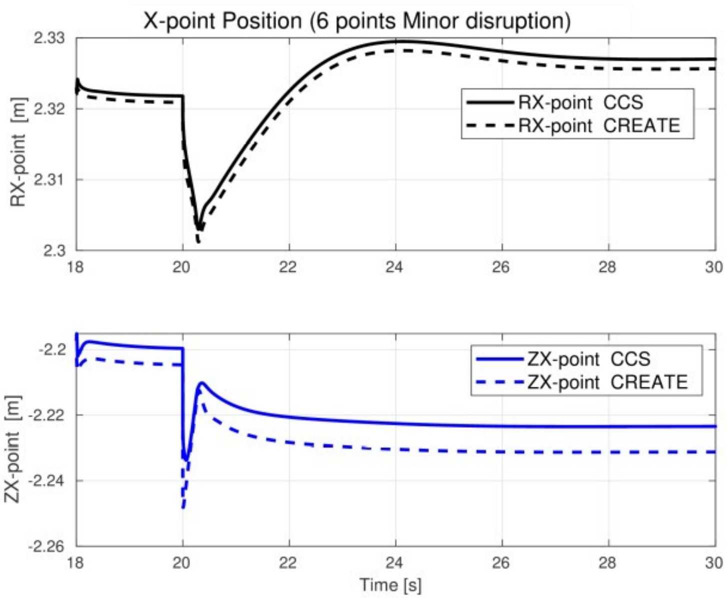




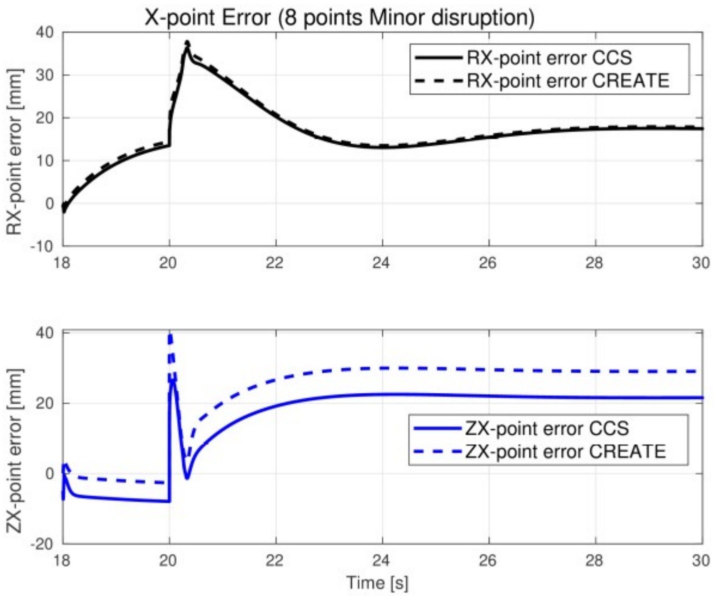
Simulation Results- X-point Position

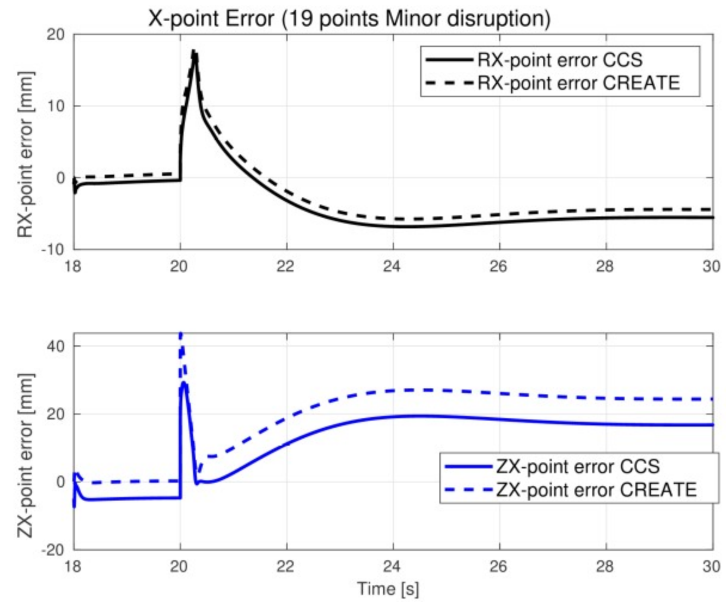


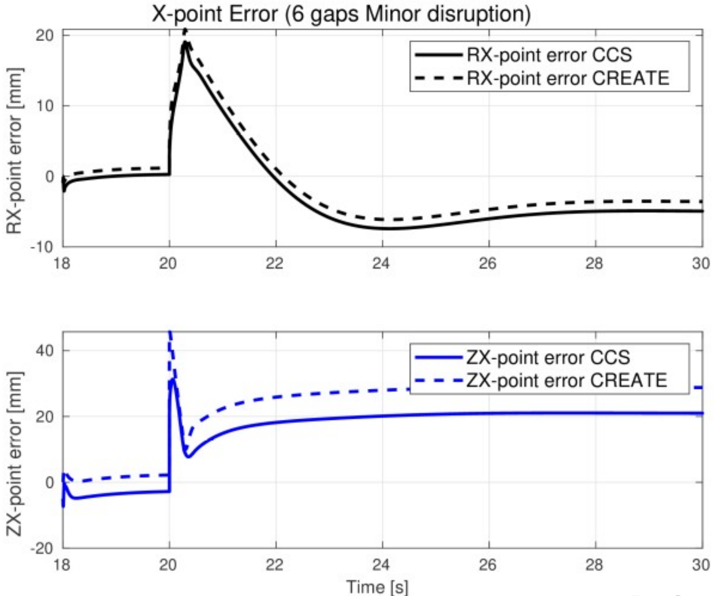




Simulation Results – X-point Error

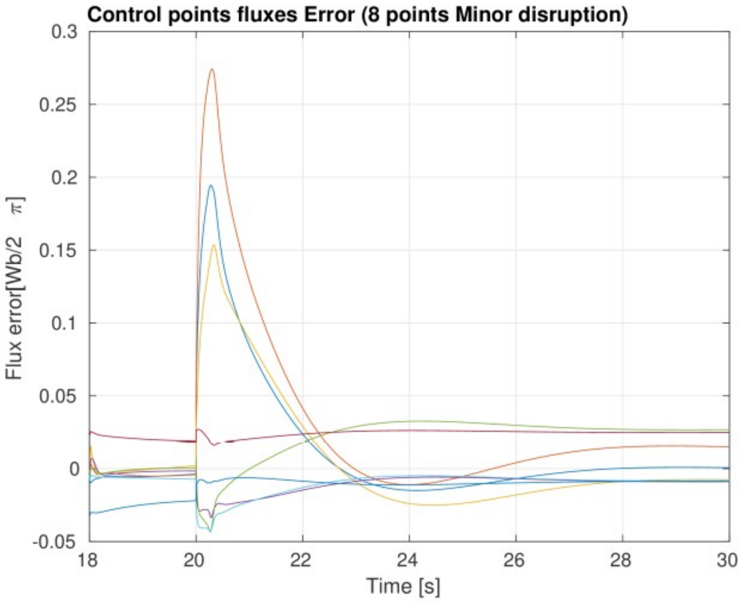


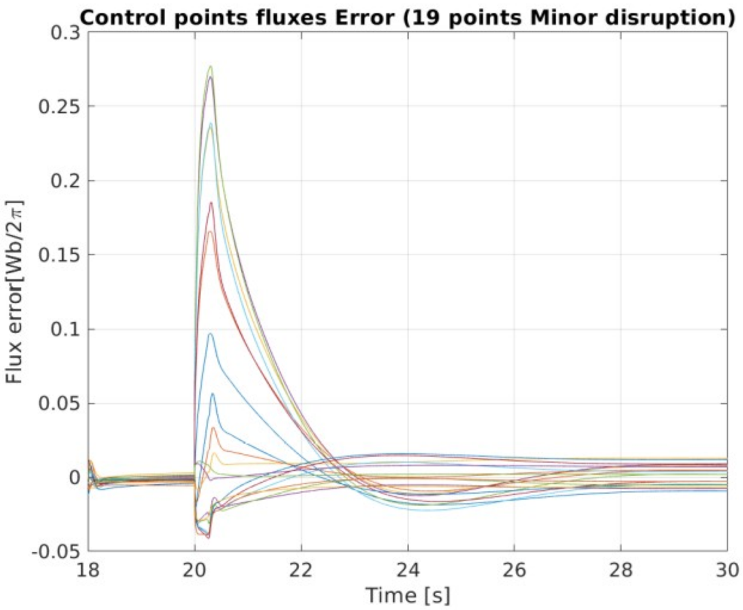


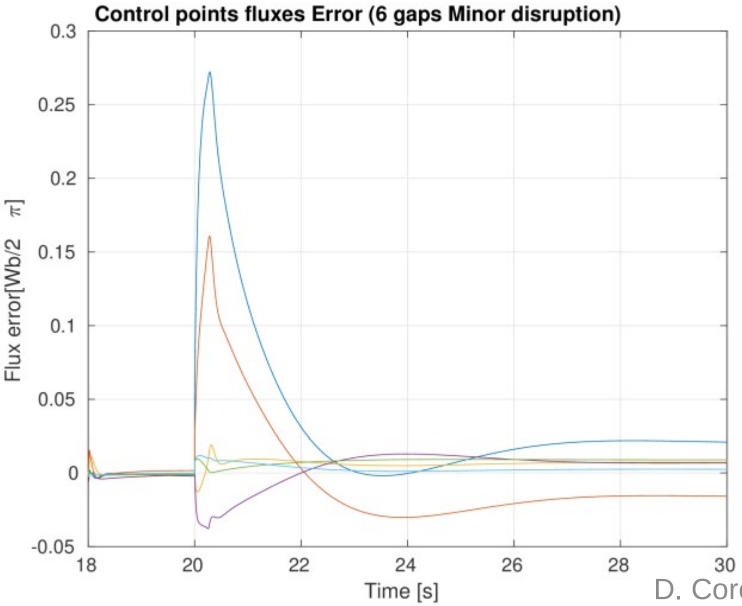


Steady State error [mm]	CCS reconstruction		CREATE reconstruction	
	RX	ZX	RX	ZX
6 points	-4.92	20.9	-3.57	28.8
8 points	17.44	21.56	17.81	29.04
19 points	-5.54	16.78	-4.42	24.41

Simulation Results – Fluxes Error







RMSE Steady State [Wb/2π]	CCS reconstruction
6 points	0.0121
8 points	0.0152
19 points	0.0069

BACKUP SLIDES

PFC current controller

- The design of the proposed PFC current control is based on a plasmaless model
- The following design approach already proposed for ITER tokamak has been adopted:

  - A modified version of the inductance matrix is calculated, by neglecting the effect of the passive structures and by
  - In order to minimize the control effort, for each circuit all the mutual inductances which are less than 10% of the circuit self-inductance have been neglected
    ✉ in this way the current in each circuit is controlled only by those circuits who are more coupled with it
  - The time constants are used to define the matrix
  - The controller is the

$$\mathbf{\Lambda} = \begin{pmatrix} 1/\tau_{PF1} & 0 & \dots & 0 \\ 0 & 1/\tau_{PF2} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1/\tau_{PF_n} \end{pmatrix}$$

where

$$\mathbf{U}_{PF}(t) = \mathbf{K}_{PF} \cdot \left(I_{PF_{ref}}(t) - I_{PF}(t)\right)$$

$$\mathbf{K}_{PF} = \mathbf{S}^{-1} \cdot \tilde{\mathbf{L}}_{PF} \cdot \mathbf{\Lambda}$$