The use of the eXtreme Shape Controller at JET

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Outline

Introduction

The *standard Shape Controller*

The eXtreme Shape Controller

Current Limit Avoidance for the XSC

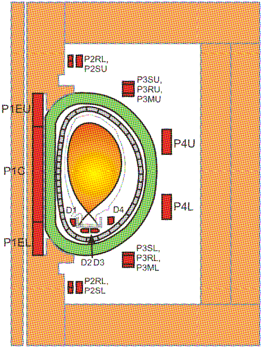
How to use the XSC

XSC scenarios

Conclusions

Plasma Shape Control

- The problem of controlling the plasma shape is probably the most understood and mature of all the control problems in a tokamak
- The actuators are the Poloidal Field coils, that produce the magnetic field acting on the plasma
- The controlled variables are a finite number of geometrical descriptors chosen to describe the plasma shape



Objectives

- Precise control of plasma boundary
- Counteract the effect of disturbances (β_p and l_i variations)
- Manage saturation of the actuators (currents in the PF coils)

Plasma Shape Control at JET

At the JET tokamak two different shape controllers are available

- the *standard* Shape Controller (SC)
- the eXtreme Shape Controller (XSC)

Shape Controller "philosophy"

With the *Shape Controller* (SC)

- each PF circuit is used to control a single variable (current, gap, flux)
- up to 9 different variables can be controlled
- since plasma current is always controlled (by means of the P1E circuit), up to 8 gaps can be controlled

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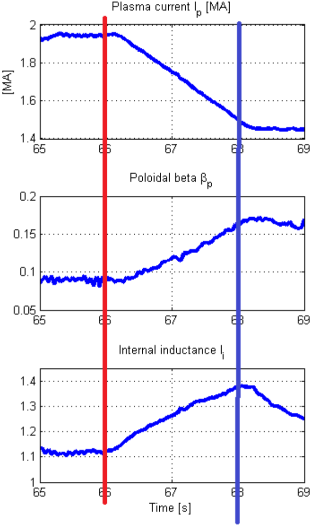
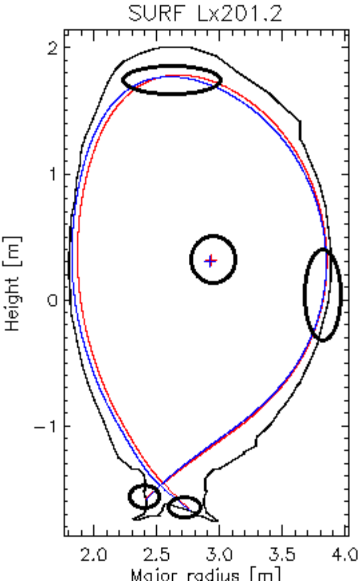
- **The controller parameters (gains) are always the same**
- **Different behaviors are obtained by changing**
  - **the control mode for the PF circuits**
  - **the reference for each control channel**

Response of the SC against the disturbances
JET shot # 78525





eXtreme Shape Controller "philosophy"

- To control the plasma shape in JET, in principle 8 *knobs* are available, namely the currents in the PF circuits except $P1E$ which is used only to control the plasma current
- The *eXtreme Shape Controller* (XSC) controls the whole plasma shape, specified as a set of 32 geometrical descriptors
- The XSC minimizes in least square sense the steady-state error on all the controlled shape descriptors

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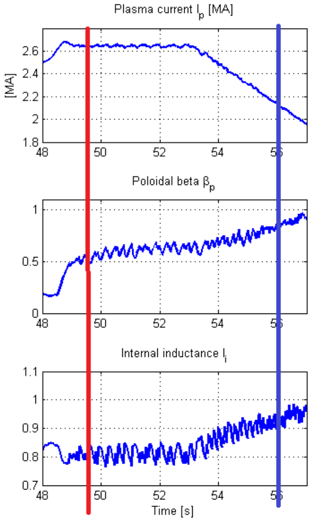
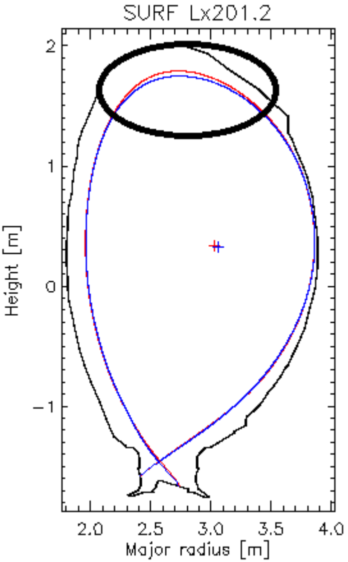
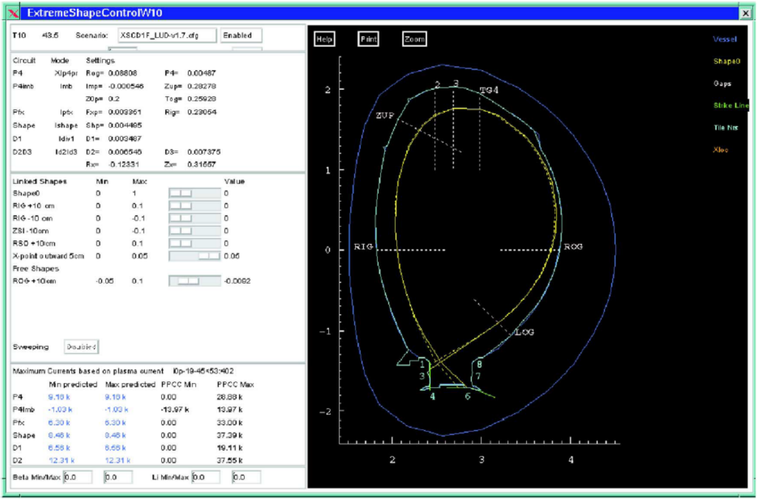
- **The design of the XSC is model-based**
- **Different controller parameters (gains) must be designed for each different plasma equilibrium, in order to achieve the desired performances**
- **No direct control on the PF currents**
- **The XSC cannot be used during X-point formation**
- **The XSC can be run only by licensed SL**

Response of the XSC against the disturbances JET shot # 72733





XSC User Interface



XSC scenarios for the 2008/09 campaigns

- XSC scenarios exist for most of the common equilibria used either in baseline H-mode or in Hybrid/AT studies
- The *most used* in the 2008/09 campaigns have been
  - `XSCD1F_ITER_RDOWN_V5_4M5_LT`, for the ITER Ramp down studies
  - `XSCD1F_HI_BPOL_LO_PFX`, for investigation of LH local heat loads
  - `XSCD1F_D1Z_C_SFE_LT`, in experiments on ELM mitigation

XSC scenarios

Excerpts of the list compiled by Fernanda Rimini (thanks!)

XSC scenario	Used for Experiment	Last used
XSCD1F_D1Z_C_SFE_LT-v1.2	EFCC ELM mitigation	79774
XSCD1F_HI_BPOL_LO_PFX_V2-v1.1	LH hot spots studies	79536
XSCD1F_HI_BPOL_LO_PFX_V2_SWEEP-v1.1	Strike point sweeping in hybrid scenarios	79615
XSCD1F_ITER_AT-v1.11	ERFA commissioning	78542
XSCD1F_ITER_RDOWN_V5_4M5_LT-v1.3	ITER ramp down studies	79201
XSCD1F_V5_3M5_HT3-v1.1	H-mode configuration development	78398
XSCD1F_V5_4M5_LT-v1.5	H-mode configuration development	72887

SC vs XSC

SC

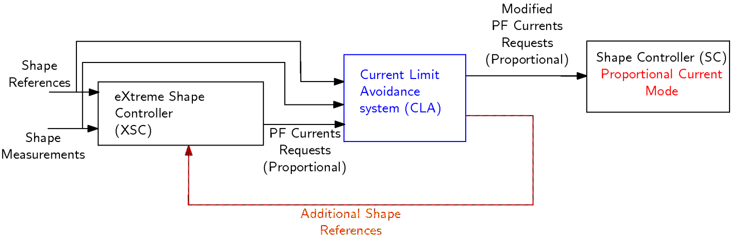
- A few geometric parameters are controlled, usually one gap (Radial Outer Gap, ROG) and two strike points
- The desired shape is achieved precalculating the needed currents and putting these currents as references to the SC
- This gives a good tracking of the references on ROG and on the strike points, but the shape cannot be guaranteed precisely
- Shape modifications due to variations of β_p and l_i cannot be counteracted

XSC

- The shape to be achieved can be chosen
- The XSC receives the errors on 32 descriptors of the plasma shape and calculates the "smallest" currents needed to minimize the error on the "overall" shape
- The controller has a better capability of keeping the shape constant even in the presence of large variations of β_p and l_i, but there is no direct control on PF currents (saturations)
- The XSC cannot be used in all the phases of a discharge
- The XSC can be run only by *licensed* SL

Current Limit Avoidance system for the XSC

- The *Current Limit Avoidance* (CLA) system has been designed to avoid current saturations in the PF coils when the XSC is used to control the plasma shape
- It uses the redundancy of the PF coil system to *automatically* obtain almost the same plasma reference shape with a different combination of PF currents
- In the presence of severe disturbances, it tries to avoid the current saturations by "relaxing" the plasma shape constraints
- **Commissioning during Restart # 2 (or 3 ?)**
- **Parasitic experiment during Restart # 4 (?)**
- CLA Project wiki page



XSC scenarios

In order to use the XSC:

- A valid (commissioned) *scenario* must be selected
- Given a scenario, it is possible to
  - change the plasma shape (according to the allowed variations)
  - switch on/off the Sweeping
  - switch on/off the Current Limit Avoidance (this feature has not been released for generale use yet)

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- The XSC scenario for the *basic* plasma scenario will be available after Restart # 2 (or 3 ?)
- Additional scenarios will be developed for the commissioning of the Current Limit Avoidance

Request a new XSC scenario

New XSC scenarios can be requested and designed.

1. An XSC request must be sent to the Plasma Operation Group (POG), specifying
   - reference pulse and time slice (for shape)
   - expected I_p, β_p, and l_i ranges
   - independent controls needed
   - limitations
   - ...
2. The XSC scenario is designed and validated in simulation
3. The XSC scenario must be commissioned before being released for general use. This requires parasitic experimental time.

Example of XSC request

XSC configuration file request

Configuration: V5_4M5_LT
Please consult the configuration approval form attached:
This configuration is limited Ip= 4.5MA
Recommendation and other current of gap limits:

Parameters for the design of the XSC

Parameters	**Ranges**
Expected range of Ip:	0.8 – 4.5MA
Expected range of B_T:	1.2 – 3.45T
Expected range of q95:	2.6 – 3.2
Expected range of beta poloidal:	1.0 – 2.0 (or higher)
Expected range of internal inductance:	0.6 – 1.2
Independent controls	ROG, RSO, ZSI, TOG
Other controls	
Reference pulses and time slice:	71197 (low li)/98(high li) @64s (ohmic) 71528/71669 (with NBI) ZSI=9 to 12cm RSO=8 to 9cm

Configuration designer: I nunes.

XSC scenario validation

In order to do the commissioning of a new XSC scenario

- A dedicated time window must be available in one or more JET shots (usually no more than three)
- The behavior must be validate by a PPCC expert

Conclusions

- The XSC allows to precisely control the plasma shape among more than 30 shape descriptors
- The XSC allows to counteract the shape variations due to β_p, and l_i *disturbances*
- The XSC may cause soft stops due to PF current saturations. This problem will be mitigate by the Current Limit Avoidance system
- New XSC scenarios need to be prepared well in advance

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- New XSC scenarios need to be prepared well in advance
- Questions ?

References

XSC at JET

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CLA Project wiki page