# T13-12 - Develop and promote the use of XSC and CLA in JET scenarios

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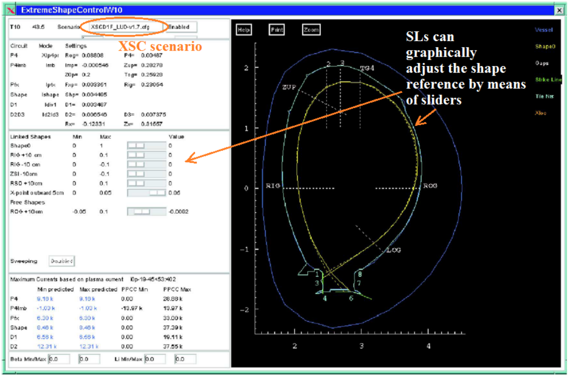
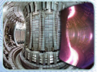
# Outline

# For those who don’t know (yet) XSC and CLA




- The XSC allows the SLs to directly specify the target shape, without specifying the PF current waveforms
- The PF current waveforms are *automatically* computed by the model-based control algorithm
- The Current Limit Avoidance System (CLA) allows **to avoid current saturations in the PF coils when the XSC is used to control the plasma shape**



# For those interested to further details...

## eXtreme Shape Controller


M. Ariola and A. Pironti
Plasma shape control for the JET tokamak
*IEEE Control Systems Magazine* vol. 25, no. 5, pp. 65–75, Oct. 2005

G. De Tommasi et al.
XSC Tools: a software suite for tokamak plasma shape control design and validation
*IEEE Transactions on Plasma Science*, vol. 35, no. 3, pp. 709–723, Jun. 2007


## Current Limit Avoidance


G. Varano et al.
Performance assessment of a dynamic current allocator for the JET eXtreme Shape Controller
*Fusion Engineering and Design*, vol. 86, no. 6-8, pp. 1057–1060, Oct. 2011

G. De Tommasi et al.
A Software Tool for the Design of the Current Limit Avoidance System at the JET tokamak
*IEEE Transactions on Plasma Science*, vol. 40, no. 8, pp. 2056–2064, Aug. 2012

G. De Tommasi et al.
First experimental results with the Current Limit Avoidance system at the JET tokamak
$27^{\mathrm{th}}$ *Symposium on Fusion Technology (SOFT'12)*,Liège, Belgium, September 2012

## Tasks goals

1. **To promote the use of XSC in the scenario development and physics studies during 2013.**
   - XSC offers a robust tool for maintaining the plasma shape against $\beta_p$ and $l_i$ variations
2. **To promote the use of CLA to enlarge the operational space for the XSC.** In particular
   - when XSC is used in high currents scenarios with low margin on the PF currents. The CLA is adopted to move the critical currents far from their limits in order to operate the given scenario in a safer way, gaining a margins for plasma shape control in case of sudden disturbances (ßp,li and Ip variations).
   - when large variations of $\beta_p$ and $l_i$ push the currents requested by the XSC close to their limits. The CLA is exploited to avoid the stop performing an automatic relaxation on the plasma boundary control.

## Scenarios developed for C28–C30

Two XSC scenarios have been designed during 2011/2012

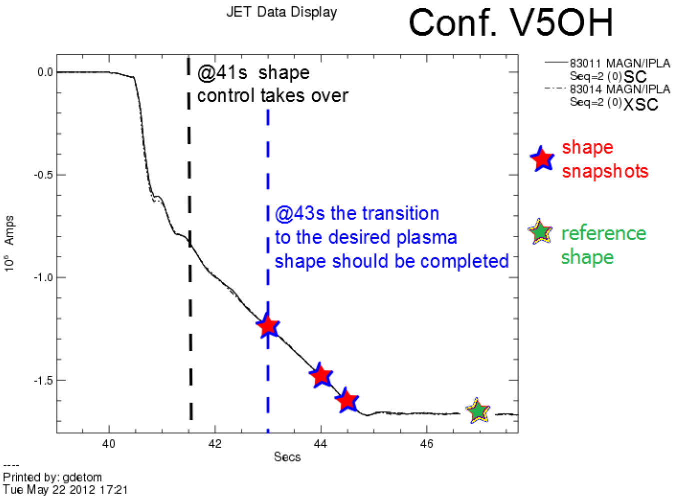
- **V5_OH_LT** (`XSCD1F_V5_4M5_LT_V2-v1.6.cfg`) – with CLA
- **V5_OS_LT** (`XSCD1F_VC_OS_LT-v1.2.cfg` – with CLA and Sweeping

# Shape control during $I_p$ ramp-up

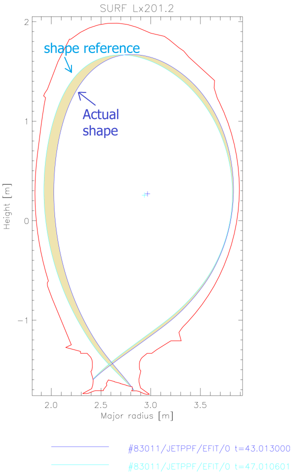
The following pulses are considered in order to compare the behavior of the two plasma shape controllers during the $I_p$ ramp-up

- #83011 – with SC
- #83014 – with XSC

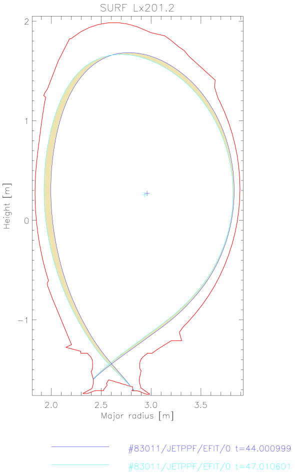
# Pulses #83011 and #83014 - $I_p$ ramp-up



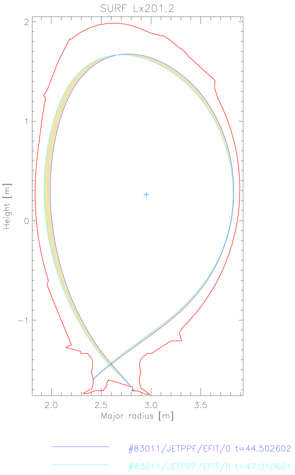
# #83011 - Shape tracking during the ramp-up with SC




@43s




@44s

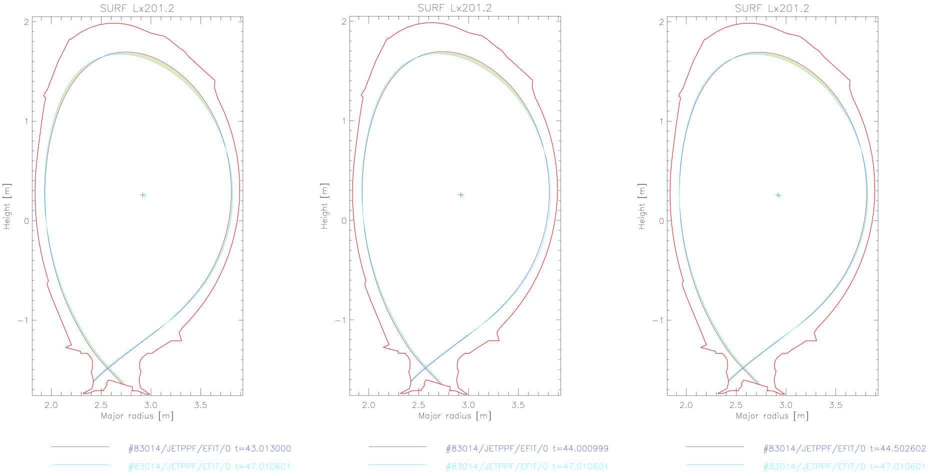



@44.5s

# #83011 - Comments

- Bad shape control in the inner side.
- This is mainly due to the fact that P4 is used to control ROG, while RIG is not controlled

# #83014 - Shape tracking during the ramp-up with XSC



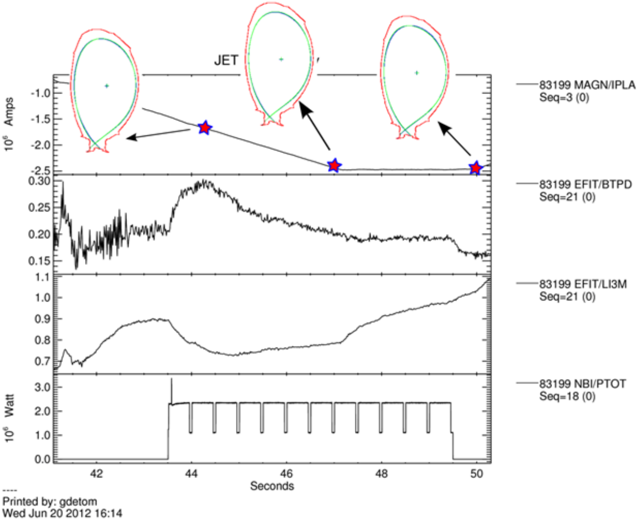

@43s @44s @44.5s

# #83014 - Comments

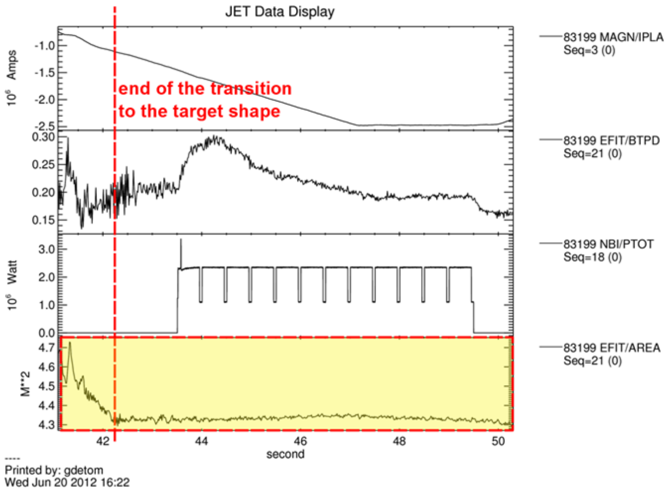
- The biggest error in shape control is in the top outer region (the XSC minimizes the shape error in least mean square sense!)
- This error could be reduced by increasing the error in a different region (i.e. in the divertor region)
- Good shape tracking in both RIG and ROG regions, and good tracking of strike points and x-point position
- **Similar results have been achieved during the $I_p$ ramp-down**. Example: compare #72203 (SC) with #83014 (XSC).

# Shape control during the ramp-up with heating – #83199

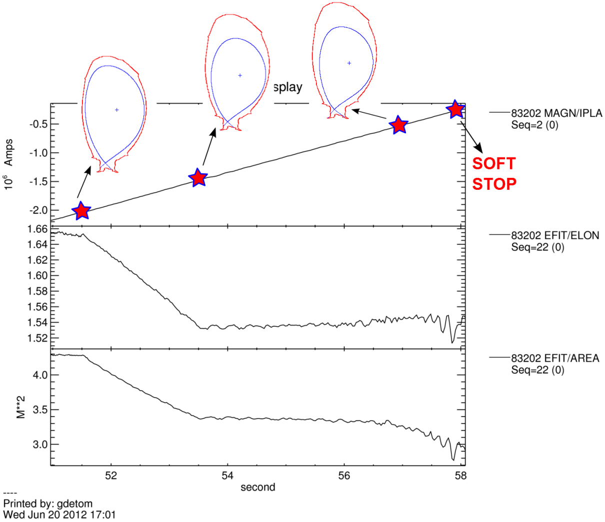
- ref. shape
- act. shape
- Maximum shape error: 3 *cm* in the top outer region, 2 *cm* on the strike points
- $\beta_p$ varies from 0.20 to 0.29 in 0.5 *s*



# Shape control during the ramp-up with heating – #83199



# Change of elongation during the plasma current ramp-down



## C28–C30: further figures

- **#83014 - XSC and CLA have been enabled at $41.5\ s$, soon after the x-point formation for the first time ever. The first pulse entirely controlled with XSC**
- From pulse 83263 to pulse 83794 (excluding dry-runs, recoveries, etc.) XSC+CLA has been used during the plasma current ramp-down
- All the experimental results are summarized on the Px-2.1.7 Wiki Page

Px-2.1.7 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 CLA

## 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 $I_p$ , $\beta_p$, 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)<br>71528/71669 (with NBI)<br>ZSI=9 to 12cm<br>RSO=8 to 9cm |

## Potential requests (received so far)

- **M13-29: Real time sawtooth control**
  - XSC + **boundary flux control**, in order to control $q = 1$ position (see Lennholm talk - 14/1/2013)
- ...

### Reference persons

- POG members (F. Rimini, F. Maviglia)
- me!

## Summarizing. . .

- By using XSC a better control of plasma shape can be achieved especially during $I_p$ ramp-up and ramp-down with large variations of $\beta_p$ and $l_i$
- Thanks to the CLA safe operations are guaranteed, and it is possible to gain margins for plasma shape control in case of sudden disturbances