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

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Outline

1. Main goals of T13-12
2. Experimental results during C28–C30
3. Development of XSC scenarios
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

- **G. De Tommasi et al.**
  XSC Tools: a software suite for tokamak plasma shape control design and validation

### 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

- **G. De Tommasi et al.**
  First experimental results with the Current Limit Avoidance system at the JET tokamak
  27th *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 ($\beta_p, l_i$ and $I_p$ 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.
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
C28–C30 experiments

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

JET Data Display

Conf. V5OH

@41s shape control takes over

@43s the transition to the desired plasma shape should be completed

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

- **C28–C30 experiments**
- **G. De Tommasi (CREATE/Federico II)**

![Graphs showing shape reference and actual shape at different times](image-url)

- **@43s**
- **@44s**
- **@44.5s**
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
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

end of the transition to the target shape
Change of elongation during the plasma current ramp-down
#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
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
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 $I_i$ 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 to $I_p = 4.5$ MA
Recommendation and other current gap limits:

Parameters for the design of the XSC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected range of $I_p$:</td>
<td>0.8 – 4.5 MA</td>
</tr>
<tr>
<td>Expected range of $B_T$:</td>
<td>1.2 – 3.45 T</td>
</tr>
<tr>
<td>Expected range of $q_{95}$:</td>
<td>2.6 – 3.2</td>
</tr>
<tr>
<td>Expected range of beta poloidal:</td>
<td>1.0 – 2.0 (or higher)</td>
</tr>
<tr>
<td>Expected range of internal inductance:</td>
<td>0.6 – 1.2</td>
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<tr>
<td>Independent controls</td>
<td>ROG, RSO, ZSI, TOG</td>
</tr>
<tr>
<td>Other controls</td>
<td></td>
</tr>
<tr>
<td>Reference pulses and time slice:</td>
<td>71197 (low $I_p$/98(high $I_p$)) @64s (ohmic)</td>
</tr>
<tr>
<td></td>
<td>71528/71669 (with NBI)</td>
</tr>
<tr>
<td></td>
<td>ZSI=9 to 12 cm</td>
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<tr>
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<td>RSO=8 to 9 cm</td>
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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!
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 $I_i$

Thanks to the CLA safe operations are guaranteed, and it is possible to gain margins for plasma shape control in case of sudden disturbances