‘Divertor Plasma Control’ Discussion

Talks covered a number of aspects of ways to improve detachment through control

- Minimize power (peak and total) density at the target ✔
- Minimize effect on the core plasma
  - Confinement ✔, impurity levels and radiation ✔, stability ✔ …
- The compression and enrichment of impurities in the divertor X
  - Maximizes divertor radiation and impurity (including He) pumping
- Easier access to detachment at the highest P_{SOL}, lowest separatrix density (n_u) and impurity concentration, C_z. Other quantities? ✔
- What detachment characteristics can be controlled in a reactor ?
- More aspects and applicability to a reactor?

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‘Divertor Plasma Control’ summary

- Detachment onset covered by Guo and Lipschultz
  - Controlling total flux expansion, strike point angle and neutral baffling can minimize (maximize) the density & impurity (P_{SOL}) detachment threshold
  - BxgradB away from the SN divertor is useful in lowering the detachment density threshold
- Detachment core radiation control covered by Bernert
  - N2-seeding allows for fine position control of the detachment-related radiation at and above the x-point; confinement degradation small even though impurity concentration significant.
- Core confinement maximized by divertor baffling
  - Better divertor baffling reduces effects on core confinement – likely due to reduced neutrals in core and hotter separatrix?

Machine	Sensor	Actuator	Scenario	Comment	Reference
AUG	X-point radiator location (AXUV)	N seeding	H-mode, full detachment	First application, ELM-free scenario?	Bernert, to be submitted to NF
AUG	T_{div} (shunt current)	N or Ar seeding	H-mode, partial detachment	Robust, only estimate of $T_{e,div}$	Kallenbach, PPCF 2010
AUG	$P_{rad,core}$ & $P_{rad,div}$ (Bolometry)	N & Ar seeding	H-mode, partial detachment	Proof of principle, worked	Kallenbach, NF 2012
JET	Langmuir probes	N seeding	H-mode, partial detachment	Only for optimised scenarios	Guillemeut, PPCF 2017
C-Mod	Bolometry/ Thermocouples	N seeding	H-mode, partial detachment	Marginally stable	Goetz, PoP 1999 Brunner, NF 2017
TCV	CIII front location (MANTIS)	D fueling	L-mode (H-mode tbd)	Optimised for a few scenarios	Ravensbergen, EPS / NF 2019
DIII-D	Divertor Thomson Scattering	D fueling	L- & H-mode	Combined with multiple sensors → Cliff-edge	Kolemen, JNM 2015; Eldon, NF 2017
DIII-D	Divertor radiation	N seeding	H-mode, f_{rad} = 50-80%	Variable geometry, unstable if core is influenced	Eldon, JNME 2019

Selected topics, not covering all experiments.

Missing here:

EAST [Wang]

Discussion topics: Control during detachment

- Control of radiation in detachment
  - Is radiation location the right thing to control?
  - Are there further metrics that need to be simultaneously controlled?
    - What are the relative priorities for characteristics we want to simultaneously control?
  - Are some actuators and measurements ‘better’ than others
  - Can we address reactor issues with control in today’s tokamaks/modelling?
    - E.g. - Slow down seeding reaction time?
  - Are there other actuators we should consider controlling during a pulse?
    - P_{SOL}? Divertor neutral pressure? Changes in divertor magnetic topology?
  - What are the positive/negatives of x-pt & above radiation?
    - How is it different than directly injecting a core radiator reducing P_{SOL}? Better or worse?
  - Other topics…

Detachment control for a reactor?

- Sensors, e.g.:
  - SOL n_e & T_e (target, X-Point & separatrix)
  - Incoming power (P_{div})
  - Impurity concentration (neutral gas, divertor plasma, core plasma)
  - Neutral gas pressure
  - Radiation location

- Actuators, e.g.:
  - Neutral gas influx/pellet flux
  - Impurity influx
  - Heating power (fast reaction)
  - Magnetic Geometry

- Controller:
  - Available and tested before scenario is applied
  - Fine tuning possible afterwards

  → Controller based on modelling results!

- Challenges:
  - Requires stable scenario
  - Actuators coupled with other control parameters
  - Limited diagnostic reliability
    → Redundant measurements
  - **Time scales of actuators most likely slower than time until melting**
    → Buffer needed

Discussion topics – divertor design to control detachment characteristics

- History of divertor design changes to optimize divertor ‘performance’ in detachment
  - Changes in the divertor structure: horizontal -> vertical divertor
  - More recently - variations in magnetic topology (‘alternative’ divertors)
- Can we be more quantitative and structured in evaluation of the importance of some divertor characteristics vs others?
- Are there more characteristics that need to be optimised specifically for a reactor?
- There has not been an in-depth study of the optimal divertor size?
  - Leg length of each divertor and their relative size
  - How ‘closed’ (a subjective assessment!) should a divertor be in a reactor where the plasma itself is a barrier for neutrals to escape?
- Why do we ignore impurity compression and enrichment in almost all studies?
- Other topics…