Partial detachment of high power discharges in ASDEX Upgrade

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Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
Introduction

- High power H-modes require radiative power removal to avoid divertor heat overload
- Actuators are core impurity radiation, divertor impurity radiation and a high divertor density
- At least partial divertor detachment is required for the dissipation of the large upstream parallel heatflux of several GW/m² in ITER/DEMO (required via $P_{\text{LH}}$)
- Operation close to full detachment may allow to use a less sophisticated high heat-flux divertor, but exhibits challenges regarding its control

This talk describes ASDEX Upgrade experiments on divertor heat flux control under conditions of high divertor radiation and heat dissipation

Particular emphasis is placed on divertor conditions between partial and full detachment, where a pronounced increase of the plasma density is observed

Experiments are done at high $P_{\text{sep}}/R$, with a standard divertor at high neutral pressure and with tungsten plasma facing components
Operational domain of high power seeded H-mode in AUG, ITER, DEMO

\[ P_{\text{sep}} / R \] is divertor identity parameter, provided similar density and power width \( \lambda_q \).
Operational domain of high power seeded H-mode in AUG, ITER, DEMO

Here: (weak) partial detachment
1/3 cryo, $p_{0,\text{div}} = 4\ \text{Pa}$

Room for stronger detachment?
→ simpler and cheaper divertor!

$P_{\text{sep}} / R = 10\ \text{MW/m}^2$!
Sketch of different detachment states (vertical target)

AUG divertor peak heat loads for different detachment states @ $P_{\text{heat}} \sim 15\text{–}20$ MW

- **Attached:** 10 MW/m$^2$ and above
- **Partial:** ~ 5 MW/m$^2$
- **Pronounced:** ~ 1-3 MW/m$^2$
- **Full:** < 1 MW/m$^2$
Pushing towards pronounced detachment

\[ H_{98} = 0.9 \text{ at } f_{GW}=0.95 \text{ and } P_{\text{heat}}=20\text{MW} \]

50% density increase due to detachment

Ongoing evolution of density, radiation and stored energy
Divertor parameters with progressing detachment from LPs

AUG divertor parameters approach ITER values

\[ P_{\text{sep}} / R = 8 \text{ MW/m} \]
Divertor radiation moves into X-point region

Partly complex, time varying changes of divertor radiation (F. Reimold, subm. to NF)

Analysis of D-Balmer lines indicates strong $T_e$ drop from midplane pedestal to X-point region
No high penalty for going from partial to pronounced detachment

- Nitrogen core concentration about 2 %
- Tungsten concentration low, but moderate central peaking after ECRH trip
Behaviour and origin of the density rise during detachment

- Supposed to be divertor physics related fueling effect (also seen in L-mode)

- Hampers AUG operation since ECRH X-2 cut-off density is exceeded (no problem for ITER or DEMO)
Density rise during detachment: predominant effect of divertor temperature, not gas puff

- only moderate increase of attached H-mode density by gas puff
- substantial density increase due to detachment, independent of gas puff
Reversible transition to pronounced detachment by core radiation

Intermittent increase of core radiation by Argon puffing → intermittent detachment
Very similar divertor behaviour compared to detachment by N

#29632 t=2.50-2.90s  #29632 t=3.70-4.00s

\[ f_{\text{sheath}} = 8.0 \]
Reduction of $P_{\text{sep}}$ by Ar radiation reduces divertor density

These changes of divertor plasma parameters will change fueling behaviour - modelling required to prove this effect to be the origin of the density rise
ELM size moderately reduced during detachment

At high neutral pressure $\geq 2$ Pa, additional core radiation leads to smaller ELMs with higher or similar frequency.

Density rise not attributed to ELM changes for the present conditions.

ELM size: pedestal effect (coll. ↑ ?)
At low neutral pressure, core radiation reduces ELM frequency

Density rise caused by lower $f_{ELM}$

not related to detachment
(but both can be combined)

Unfavourable conditions:
Large ELMs, prone to central W accumulation

Core radiator seeding should be combined with small ELMs $\rightarrow$ high $P_0$, nitrogen
Detachment indicator allows approximate prediction of its onset

\[ q_{\text{det}} = \frac{P_{\text{sep}}}{R} \left( p_0 + 18 p_{0,N} \right)^{-1} \cdot 1.3 \text{ Pa m/MW} \]

obtained by fitting of T_{\text{div}} from „engineering“ parameters – allows prediction of detachment*

Good description of AUG H-mode detachment

Not necessarily a unique solution, non-linearities possible

Modelling in progress, and better diagnostics desirable for better understanding

The passive divertor electric current measurement proves very useful for heat load control, and offers good opportunities for detachment control

*Not to be confused with „degree of detachment“, DoD, A. Loarte et al., NF 38 (1998) 331
Conclusions

• About 2/3 of the ITER value of divertor power loading $P_{sep}/R$ have been handled in ASDEX Upgrade with a target peak power load well below $10 \text{ MW/m}^2$

• Power dissipation is achieved by a combination of high deuterium neutral pressure and nitrogen seeding, taking advantage of a versatile feedback system

• Looking towards DEMO, operation with almost complete divertor detachment offers possibilities to relax divertor requirements – allowing a simpler and cheaper technical solution

• This comes at the cost of a higher $Z_{eff}$ and moderately reduced performance in AUG and enhanced challenges for the control system

• Confinement predictions for DEMO under these conditions require future work
Backup slides
Tdiv obtained from thermoelectric current by scaling and ELM filtering

ELM filtering in real time with LabVIEW RT
Origin of the passive divertor electric current?

- Itar consists of thermo-electric and Pfirsch-Schlüter contributions
- Thermo-current flows along SOL field lines between outer and inner divertor
  It is driven by electrons on hot end (outer divertor)
Origin of the passive divertor electric current

- During detachment, the thermo-electric component vanishes
- Slight imbalance of PS currents or far SOL thermocurrents with divertor as cold end lead to slightly negative total values, used as detachment monitor
Radiative power loss function $L_z$, (corona) equilibrium

Application for plasma cooling depends on $L_z$ at low and high $T_e$

Krypton good core radiator

Nitrogen good divertor radiator

Argon could do both with good divertor compression

Calculated from ADAS using a collisional radiative model, summing over many emission lines, Recombination induced radiation and bremsstrahlung