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[REGULAR POSTER TWIN] Control of the X-point radiator in fully-detached ASDEX Upgrade H-mode plasmas

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Power exhaust is one of the big challenges for future fusion reactors. In the EU programme, both conventional and alternative divertor approaches are studied. For a conventional divertor in EU-DEMO (1), more than 80% of the exhaust power needs to be dissipated before entering the SOL to keep the divertor in the detached regime, where the interaction of the plasma with the wall is significantly reduced (2). As the detached state needs to be sustained, it is essential to implement a real time control scheme which also allows for a sufficient margin to operate the device.

Radiation is the dominant energy dissipation process in a reactor relevant tokamak plasma. It can be increased by seeding of impurity gases. If the complete detachment is achieved by the injection of impurities into tokamaks with a full metal wall (such as ASDEX Upgrade (AUG) or JET), the divertor radiation concentrates in a small region at or above the X-point inside the confined region (3)(4), see Fig. 1. This so-called X-point radiator can be induced at AUG through nitrogen or argon seeding and presents within boundaries a stable regime of operation. This is contrary to carbon wall operation in which X-point radiation or a so-called MARFE is usually observed to lead to disruptions. Hence, in the operation with a tungsten wall, a reliable control of the X-point radiator is crucial for the success of the conventional divertor solution.

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The vertical extent of the X-Point radiator at AUG is about 5cm and it can move further into the confined region; the vertical distance of the radiating region to the X-point depends, among other parameters, on the impurity influx and heating power. The radiator can be stably held up to 15cm above the X-point, corresponding to a normalized flux surface radius of ϱpol≈0.99.

In order to test the controllability of this regime and to gain a deeper understanding of the physics behind the X-point radiator, a real time control scheme has been implemented in AUG. The controller utilizes an array of poloidally-viewing AXUV diode bolometers to detect the location of the radiation peak in the vicinity of the X-point. The nitrogen seeding level is used as the actuator to move the radiation region either further into the core plasma or back towards the X-point, see Fig. 2. The details of the feedback control system and effects on the divertor and core plasma will be presented.

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The new controller shows for the first time the active control of a fully detached state in H-mode. This will be compared with other existing detachment controllers, for example the control of the onset of detachment using the CIII emission front at TCV (5), and the possible application for future devices.

When the radiator penetrates strongly into the confined region (reaching 7cm above the X-point, which is at the foot of the pedestal at ϱpol<0.997), it is observed that the pedestal stability is modified, leading to reduced pedestal pressure gradients but similar performance further inside the confined plasma (4). In this regime, ELMs are suppressed (see bottom graph of Fig. 2). The ELM suppression avoids the intermittent heat fluxes of ELMs into the divertor, which would otherwise lead to a transient re-attachment of the divertor and significantly reduce the lifetime of a divertor in future reactors. This regime is currently being examined and will be discussed further.

The movement of the X-point radiator provides an operational margin between the beginning of complete detachment, where the radiator develops at the X-point, and a radiative collapse, where the radiator penetrates too far into the confined plasma. Thus, if it is possible to operate a future reactor in this regime without having detrimental effects, e.g. on the energy confinement, a real time controller could be implemented to regulate the position of the radiator and ensuring stable operation with a detached divertor at maximum radiated power fractions, possibly already incorporating ELM mitigation.

These experiments open up the possibility to reliably reduce the power flux across the separatrix such that a conventional divertor solution may be possible in EU-DEMO. At the same time, they also alleviate the challenge for alternative divertors.

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