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Mitigation of Edge Localized Modes with new active in-vessel saddle coils in ASDEX Upgrade

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One of the challenges for ITER and a fusion reactor is the potential of severe life-time limitations of the first wall and divertor due to excessive thermal loads by Edge Localized Modes (ELMs). While ELMs have been sucessfully mitigated or even suppressed by application of non-axisymmetric magnetic perturbations [1], the physics base for this technique is still sparse and extrapolation towards ITER uncertain. In order to broaden the experimental data base, ASDEX Upgrade is being extended with a set of 24 in-vessel saddle coils [2]. A first set of eight in-vessel saddle coils, four coils at the low field side above and four coils below midplane, has been operational since the 2011 experimental campaign, together with a fully tungsten-coated first wall. This configuration allows for $n = 1$ and $n = 2$ perturbation fields with zero or 90 degrees toroidal phase shift between upper and lower arrays (even or odd parity). Application of stationary $n = 2$ perturbations leads to mitigation of type-I ELMs in plasmas with moderate to high edge densities [3]; Greenwald density fraction $n/n_{GW} \geq 0.65$, and neoclassical pedestal electron collisionalities $\nu_{\mathrm{e,neo}} \geq 1.2$. With saddle coils off, the ELMs are of type I, with stored energy loss per ELM ranging from 30 to 100 kJ, and peak power loads to the inner divertor of up to 10 MW (area-integrated). With saddle coils (coil current 4.5 kA$\times$turns), the frequency of type-I ELMs gradually decreases and eventually they completely disappear. In between or instead of these large ELMs intermittent high frequency transport events are observed, with similarities to those in small ELM regimes and more continuous power load. The inner divertor remains completely detached. Plasma density and stored energy with coils on is not reduced compared to unmitigated type I ELM phases. The tungsten concentration is lower in ELM-mitigated phases than in unmitigated type I ELM phases. Pellets of different size have been injected into an ELM-mitigated phase; no large ELMs are triggered. So far, ELM mitigation has been observed with in a wide range of edge safety factors, $q_{95} = 3.7 - 6.2$. Direct comparison of optimum resonant and non-resonant fields (odd and even parity at $q_{95} = 5.5$) shows no difference of coil current threshold to access the ELM mitigated regime. The properties of these discharges are comparable to the high collisionality regime in DIII-D [4]. Current experimental work in ASDEX Upgrade aims to also reproduce and study the low collisionality ELM suppression regime.

[1] Editorial, Nucl. Fusion **49** (2009) 010202
[2] SUTTROP, W. et al, Fusion Eng. Design **84** (2009) 290, and references therein
[3] SUTTROP, W. et al, Phys. Rev. Lett. **106** (2011) 225004
[4] EVANS, T. et al, Nucl. Fusion **45** (2005) 595