Progress and challenges in understanding the Quasi-Continuous Exhaust regime

M.G. Dunne
Max-Planck-Institute for Plasma Physics, Garching, Germany
mike.dunne@ipp.mpg.de

Developing regimes devoid of large ELMs which are compatible with metal walled operation is of paramount importance for the reliable operation of future fusion devices. The quasi-continuous exhaust regime (QCE), well established at AUG[1], TCV[2], and JET[3], is emerging as a promising H-mode operational regime which combines high pedestal top pressure with exhaust-relevant high separatrix density.

This contribution will introduce a general conceptual model for ELM-free scenarios where a large-scale MHD instability, which would lead to an ELM crash, is avoided by increasing transport in the pedestal region. For the QCE, several avenues of investigation into the nature of this increased transport are open, focusing principally on ballooning modes close to the separatrix.

Characterisation of the temperature and density close to the separatrix show a critical collisional broadening at ASDEX Upgrade upon entry into the QCE regime. At the same time, ideal MHD calculations show local ballooning modes unstable at the separatrix in the QCE. Fluctuation measurements also show a mode at the separatrix which is consistent with a kinetic ballooning mode description, fitting with the MHD analysis. An MHD-based model can be used to explain the requirement of high plasma shaping and, combined with a collisional-broadening-based scaling for the temperature and density gradients at the separatrix, the required high separatrix density which is hypothesised to drive a ballooning mode.

Based on the improved understanding of the nature of the transport mechanism in the QCE, experimental progress has been made at AUG, TCV, and, more recently, JET. The JET experiments, in particular, have demonstrated the QCE at plasma currents up to 2.25 MA, q_{95} values down to 3.3, and pedestal-top collisionalities lower than those possible on AUG and TCV (reaching values of 0.7, compared to an expected pedestal top collisionality of 0.1 in ITER), highlighting the relevance of the QCE as a reactor-relevant scenario.

The combination of MHD and parameterised separatrix gradients allows the QCE operational space to be investigated for any device. Projections to future devices will be shown, along with an outlook for open research areas in the QCE regime. Exploration of the regime at even lower pedestal collisionality would be extremely beneficial and is a research topic which will become possible with the next generation of tokamaks which are currently being built and commissioned. Integration of a detached divertor with the QCE regime is of particular importance, as well as an LH transition directly into the QCE during e.g. the current ramp-up in ITER. These topics can be addressed both by extended modelling of the regime, based on our latest understanding, and targetted experiments on various devices to continue to validate our understanding.

[1] M. Faitsch, et al. *Nuclear Fusion*, 63(7), may 2023.

[2] B Labit, et al. *Nuclear Fusion*, 59, 8 2019.

[3] M. Faitsch, et al. *Nuclear Fusion*, 65, 2025.