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Alternative divertor configurations improve power exhaust control

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Managing power and particle exhaust from the core fusion plasma towards the reactor wall remains a critical challenge for realising fusion energy. In the presence of power transients, active control of the exhaust is essential as a loss of plasma detachment can result in target destruction while too cold conditions can trigger a disruption which damages the device. Alternative Divertor Configurations (ADCs) can greatly ease power exhaust control through their superior performance in comparison to conventional divertors [1,2].

Our work on MAST-U successfully demonstrates power exhaust control in the Super-X and Elongated ADCs. This is achieved through novel sensor techniques, enabling control of the cold, detached buffer plasma positioned between the target and the X-point in real-time, employing D_2 Fulcher emission as a proxy for the ionisation region front. In contrast, exhaust control was not possible in the conventional divertor scenarios on MAST-U as the divertor state was too sensitive to perturbations, giving actuators insufficient response time.

Our results show that ADCs tackle key risks for fusion power exhaust control: Their highly reduced sensitivity to perturbations enables active exhaust control where conventional divertors fall short. Furthermore, the increased passive absorption of transients is a major benefit, especially when they are too fast for gas actuators to compensate.

We also observe a strong neutral density isolation of each divertor from other reactor regions. This is illustrated in Figure 1 where we show power-exhaust control through a D_2 gas valve positioned in the lower divertor chamber. The divertor chamber actuation does not significantly affect the core plasma density, contrary to previous main chamber gas valve results [2]. This enables nearly independent control of the divertors and core plasma, essential to compensate the asymmetric power transients expected in reactors with Double-Null divertor configurations due to up/down asymmetries.

Our work showcases the real-world benefits of ADCs for effective heat load management and highlights them as a promising solution for power exhaust in fusion power reactors.

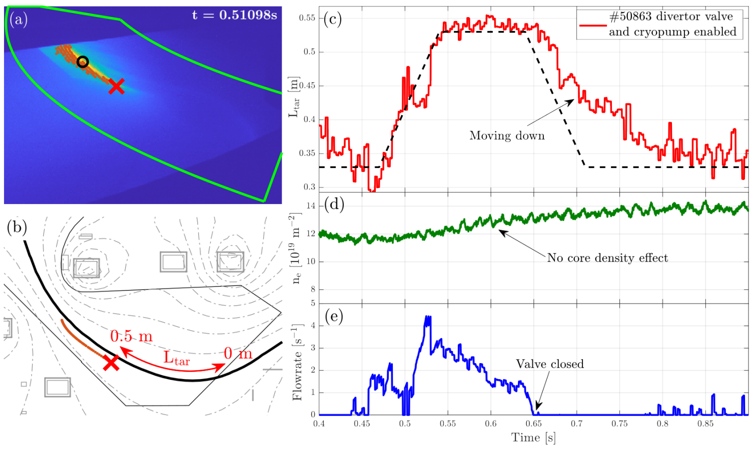

Figure 1: Exhaust control in the MAST-U Super-X divertor using cryopumping and divertor fueling. (a) D_2 Fulcher-band filtered image of the lower divertor, showing the tracking area (green box) [3], maximum intensity (black circle), detected divertor leg (orange dots), and the detected emission front (red cross). (b) Corresponding divertor cross-section with magnetic divertor topology (black), detected divertor leg (orange dots), and the detected emission front (red cross). The red arrow indicates the distance-to-target measurement L_{tar}. (c) Time evolution of the emission front position (L_{tar}) compared to the reference signal (dashed). Cryopumping also allows the front to be moved down, closer to the target, contrary to non-cryopumped experiments [2]. (d) Line-integrated core density, showing no significant response from divertor actuation, contrary to midplane fueling experiments where the core density response resembles the injected fueling trace [2]. (e) Gas flow request to the lower divertor valve by the exhaust controller.

References

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