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The Small Angle Slot Divertor Concept for Steady-State Fusion

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A major challenge facing the design and operation of future high-power steady-state fusion devices is to develop a robust boundary solution with an order-of-magnitude increase in power handling capability relative to present experience, while having acceptable erosion at the surface of the plasma facing components (PFCs) to ensure an adequate reactor lifetime. Recently, a small angle slot (SAS) divertor concept has been developed to enhance neutral cooling across the divertor target by coupling a closed slot structure with appropriate target shaping in the near SOL [1]. First results from DIII-D [2] find that cross-field drifts can have a significant effect on particle fluxes and pressure enhancement in the SAS, favouring operation with the ion grad-B drift away from the X-point, as currently employed for advanced tokamaks. SAS allows for transition to low temperature moderately detached divertor conditions with Te ⊠ 10 eV at very low main plasma densities, lower than are usually attainable at all in the DIII-D high confinement (H-mode) plasmas used in these tests. In addition, pedestal performance and core confinement are significantly improved, and the final confinement collapse associated with the onset of an X-point MARFE occurs at significantly higher pedestal densities than for other divertors in DIII-D, thus widening the window of H-mode operation compatible with a dissipative divertor. For operation with the ion grad-B drift toward the X-point, the divertor plasma transitions to a bifurcative detached state at much higher densities, similar to other divertor configurations in DIII-D. Initial modelling with SOLPS-ITER including drifts shows that SAS can achieve a (highly dissipative) detached state across the target for the ion grad-B drift away from the X-point, while remaining (partially) attached for the opposite drift direction at a given upstream separatrix density, qualitatively consistent with the experimental observations. The modelling highlights how plasma drifts interact with closed divertor structures affecting overall particle transport and divertor dissipation. SOLPS modelling for CFETR [3] has shown that a SAS-like divertor configuration can also improve divertor dissipation, achieving Te < 5 eV across the divertor target plate, which is essential for steady-state operation, with respect to an ITER-like divertor configuration where Te remains high away from the strike point. Efforts are being made to develop the modeling tools needed for rapid evaluation of 2D-fluid divertor simulations and to develop reduced models to gain physics insights for use in guiding the divertor design and optimization for CFETR, as well as the next-step steady-state high-power density fusion device under consideration in the US.

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[1] Guo H.Y. et al 2017 Nucl. Fusion 57 044001
[2] Guo H.Y. et al 2019, First experimental tests of a new small angle slot divertor on DIII-D, Nucl. Fusion https://doi.org/10.1088/1741-4326/ab26ee
[3] Ding R. et al, "Recent progress on divertor physics design of CFETR", this workshop.

Affiliation

Country or International Organization

United States of America

Author: Mr GUO, Houyang (General Atomics)

Co-authors: MA, X.X. (Oak Ridge Associated Universities); Mr ADAMS, Mark (General Atomics); DING, Rui (Institute of Plasma Physics, Chinese Academy of Sciences); Mr GUTERL, Jerome (Oak Ridge Associated Universities); Mr LAO, Lang (General Atomics); Mr LEONARD, Tony (General Atomics); SANG, Chaofeng (Dalian University of Technology); STANGEBY, Peter (University of Toronto); Mr THOMAS, Dan (General Atomics, USA); Dr WANG, Huiqian (General Atomics, San Diego, CA 92186 USA)

Presenter: Mr GUO, Houyang (General Atomics)

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