Experimental Verification of Three-Dimensional Impurity Flows Due to Temperature-Driven Pressure Gradients

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Fluid modelling predictions of 3D flows due to parallel pressure gradients have been confirmed experimentally in the DIII-D tokamak using 2D Coherence Imaging Spectroscopy (CIS). 3D flows are of particular concern for large and next-generation stellarators where momentum loss from counter-streaming flows near magnetic islands can result in high-temperature detachment before onset of a high-recycling regime [1]. In tokamaks, the 3D flows in resonant magnetic perturbation (RMP) ELM-suppressed H-modes have been associated with the emergence of lobe-structures in the SOL and have been proposed as a possible mechanism for RMP-induced density pump-out [2].

On DIII-D, 3D flow effects have been observed during n=2 RMP ELM-suppressed H-mode discharges and in the presence of of large coherent n=1 magnetic islands. These islands were produced by external RMP coils during an L-mode inner-wall limited plasma. Using the CIS diagnostic, velocity images were obtained for a variety of island locations extending from the limiting surface to the far-SOL. A poloidally-alternating pattern of acceleration and deceleration, correlated to island positions, was observed with local velocity changes up to 10km/s and a scale length of 30-40cm at the mid-plane. Rotational screening inhibits the formation of 3D flows indicating that island formation, not simply 3D fields, is required.

These velocity perturbations were predicted with EMC3-EIRENE fluid modelling where 3D flows are generated by parallel pressure gradients resulting from the small temperature gradient across magnetic islands and an inboard/outboard density asymmetry. These parallel pressure gradients drive counter-streaming flows in island chains confined within the separatrix and flow velocity perturbation in the partially-stochasized SOL where the finite connection length of open field lines becomes an important contributor.

Quantitative comparison between EMC3-EIRENE and CIS measurements achieved using a newly-developed synthetic diagnostic reveals differences in the velocity perturbation's absolute magnitude of about a factor of 2. Other discrepancies reveal the importance of correctly simulating both poloidal and radial T_e profiles and suggest the need for inclusion of cross-field drifts for full-device modelling. Despite these differences, the pattern of alternating velocity perturbations throughout the SOL is captured, consistent with the role of parallel-pressure gradients in driving 3D flows.

[1] Y. Feng, et al., Plasma Phys. Control. Fusion. 024009 (2011) 53
[2] O. Schmitz, et al. Nucl. Fusion. 066008 (2016) 56

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