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Hall MHD Simulations of MARFE Dynamics in Limiter and Divertor Configurations

Yiming Zu[1], Zhiwei Ma[2], Wei Zhang[2], Wenjin Chen[3], Yuchen Xu[1], Ge Zhuang[1]
[1] School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, China
[2] Institute for Fusion Theory and Simulation, Zhejiang University, Hangzhou, China
[3] Southwestern Institute of Physics, PO Box 432, Chengdu, Sichuan, China
e-mail (speaker): ymzu@ustc.edu.cn

In toroidal magnetic confinement fusion devices, plasma density is constrained by an upper limit known as the density limit [1]. Approaching this limit can lead to disruptions [2]. While the fundamental physics of the density limit remains unclear, experimental studies have shown a strong correlation with edge impurity radiation [3]. This radiation can lead to the formation of MARFE (Multifaceted Asymmetric Radiation From the Edge) [4]. Observations on devices like J-TEXT [5] and EAST [6] have indicated that density limit disruptions often occur following MARFE movement; however, the relationship between MARFE dynamics and these disruptions is not well understood. In this study, we employ the impurity Hall MHD code CLT to investigate MARFE movement under both limiter and divertor configurations [7].

We simulate the MARFE movement experiment on J-TEXT and validated the simulation by comparing the line-averaged density and line radiation intensity between the simulation and the experiment. It is found that impurity radiation cooling enhances the Hall effect, leading to the MARFE movement. Impurity radiation cooling causes the plasma to contract and the locally enhanced distribution of the current density. When the enhanced current approaches close to the q=2 resonant surface, the tearing mode is excited. Therefore, both MARFE movement and tearing mode excitation are driven by edge impurity radiation, which may explain why the density limit disruption on J-TEXT often occurs after MARFE movement.

We also simulated MARFE movement in a divertor configuration with the X-point. The results show that impurity radiation cooling at the X-point generates a poloidal velocity flow towards the high-field side. This velocity is mainly driven by the impurity radiation cooling while the Hall effect can be ignorable. When temperature cooling is strong, this poloidal velocity is significant enough to drive MARFE towards the high-field side. Otherwise, MARFE remains located at the X-point.

In the limiter configuration, wall-injected impurities form MARFE at the high-field-side midplane. Temperature cooling drives a symmetric poloidal flow, and the Hall effect breaks this symmetry to move MARFE. In the divertor configuration, X-point impurities produce a poloidal flow toward the high-field side via radiation cooling, with minimal Hall influence-so MARFE movement is driven locally by cooling. Because radiation cooling is field-direction-independent yet experiments show field-direction effects on MARFE, we are now exploring ion diamagnetic drift as the driving mechanism.

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References

[1] Greenwald M. Plasma Phys. Control. Fusion 44 R27 (2002)
[2] Suttrop W *et al*, Nucl. Fusion 37 119 (1997)
[3] Wesson J.A. *et al*, Nucl. Fusion 29 641 (1989)
[4] Lipschultz B. *et al*, Nucl. Fusion 24 977 (1984)
[5] Shi P. *et al*, Nucl. Fusion 57 116052 (2017)
[6] Hu W *et al*, Chin. Phys. B, 32: 075211 (2023)
[7] Zu Y et al, Nucl. Fusion, 65: 036005 (2025)

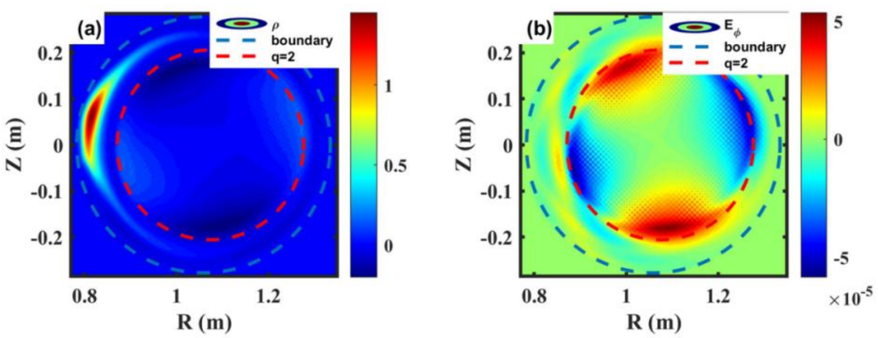

Figure 1. The (a) density perturbation and the (b) toroidal electric field on J-TEXT limiter configuration. The density perturbation reflects the movement of the MARFE, while the toroidal electric field indicates the excitation of tearing modes.