EFFECTS OF THE MULTI-MODE ISLANDS ON THE RUNAWAY ELECTRON SUPPRESSION ON J-TEXT

[1]Z. F. LIN*, [1]Y. YANG, [2]J. H. YANG, [2]H. C. WANG , [2]X. P. JIANG, [2]Z. H. JIANG, [2]Z.Y CHEN, AND [2]J-TEXT TEAM

[1] School of Electrical Engineering & Automation, Jiangsu Normal University, Xuzhou, Jiangsu, China

[2] International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, China

Email: zflin@jsnu.edu.cn

1. INTRODUCTION

Runaway electrons (REs) generated during disruption may cause severe damage to the plasma-facing components. Avoiding and suppressing REs during disruptions is essential for future tokamaks [1]. Mode-locking is considered one of the most common cause of disruptions. Studying the effect of locking mode islands on the runaway current suppression is of great important for the implementation of disruption mitigation system. NIMROD simulations had demonstrated that the pre-existing locking islands will significantly affect the evolution of cooling process, the appearance of higher-*n* harmonic modes and the regions of stochasticity, so that affect the REs seed loss [2,3]. These simulations focus on the effect of single-mode islands on the disruptions. However, locking mode disruptions typically include multiple mode islands which will together influence the process of disruptions and the generation of REs. Therefore, a systematic study combining simulations and experiments was conducted on J-TEXT to investigate the impact of the multi-mode islands on the runaway current formation.

2. COMPUTATIONAL MODEL AND EXPERIMENTAL SETUP

In the simulation, the MHD code NIMROD, the Monte Carlo particle-following code ASCOT5 [4], and the kinetic-fluid runaway electron model DREAM [5] together provide a self-consistent description of MHD evolution, runaway electron transport [6], and global runaway current dynamics. The ASCOT5 code was used to evaluate RE transport coefficients based on NIMROD 3D fields, and these coefficients were incorporated into DREAM simulations of RE generation and evolution. The REs seed loss can be obtained through the NIMROD simulation, and the runaway current considering the RE generation mechanism can be achieve by the DREAM simulation. In the experiment, the 2/1 mode resonant magnetic perturbation (RMP) was applied to excite a fixed-phase 2/1 mode island. Additionally, the 3/1 mode island is implanted by other RMP coils which can adjust its phase by changing the current direction.

3. RUNAWAY CURRENT SUPPRESSION BY THE MUTI-MODE

Simulation result -- In the simulations, the 2/1 and 3/1 island O-points were locked in the poloidal direction and rotated poloidally together. The relative phase between the O-point of the multi-mode and the MGI valve can be described as $\Delta\theta = \theta_{\text{O-point}} - \theta_{\text{MGI}}$. When $\Delta\theta = 0°$， the O-points of 2/1 and 3/1 mode islands are in phase with the MGI deposition. NIMROD results in Fig. 1(a) show that the muti-mode's phase and size can significantly affect the RE seeds loss. When the O-point of 2/1 mode islands is aligned with the MGI valves, the least RE seeds will remain. Taking into account the influence of the RE generation mechanism, the DREAM simulations further reveal that the runaway current is strongly phase-dependent, and the most effective suppression of RE current occurs when the multi-mode's O-points coincide with the MGI port (Fig. 1b). The alignment of locked island O-points with the injection location will enhances the evolution of magnetohydrodynamic (MHD) instabilities, leading to RE seed dissipation and suppression of runaway current during the current quench.

Experimental result – The X-point of 2/1 mode islands remains fixed in phase with MGI location. The phase and size of 3/1 mode island are changed by the RMP current direction and amplitude, respectively. When the current of 3/1 mode RMP is positive, the O-point of 3/1 mode islands aligns with MGI location. Conversely, the X-point of the 3/1 mode islands aligns with the MGI when the current is negative. As shown in Fig. 2, runaway-free disruption happened when the O-point of 3/1 mode island aligns with the MGI. However, RE suppression was ineffective when the X-point of the 3/1 mode island is in phase with the MGI.

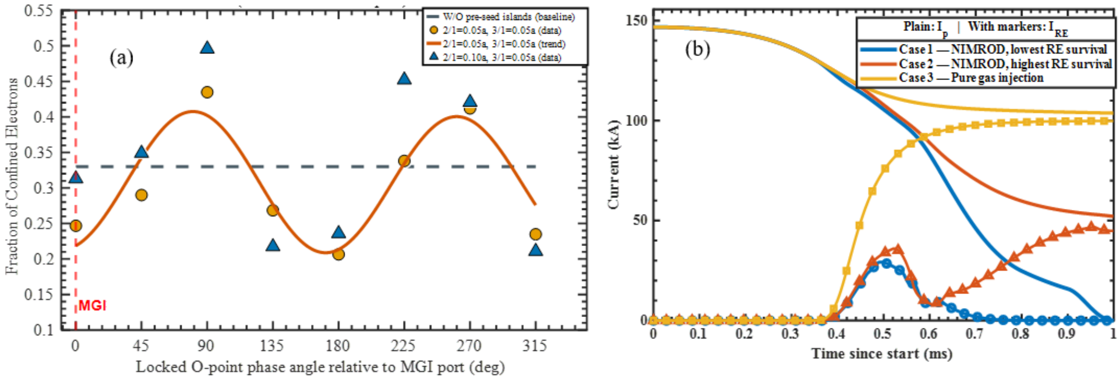

Figure 1. (a) NIMROD simulation: fraction of confined RE seeds versus relative phase Δθ. (b) DREAM simulation: temporal evolution of runaway current in the cases of Δθ = 0° (blue), Δθ = 90° (red), and pure MGI injection (yellow).

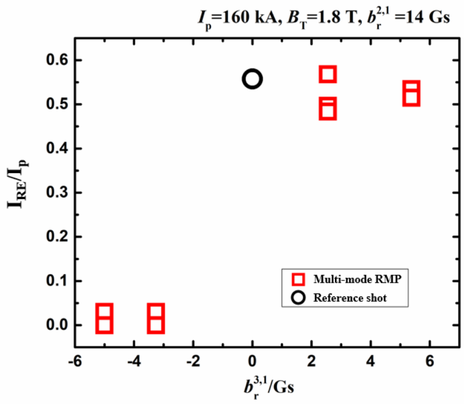

Figure 2. Experimental result: the relationship between the runaway current and the phase and strength of 3/1 mode RMP.

4. CONCLUSION

The efficiency of runaway current suppression by the multiple modes is related to the island's phase and size. The 2/1 mode's phase and size play a dominant role in RE suppression. The optimal phase for the RE seed loss is $\Delta\theta$ = 0° or 180°, which corresponds to the O-points of 2/1 mode island aligning with the MGI location. When the X-point of 2/1 mode islands is in phase with MGI valve, the runaway current can persist. In order to suppress RE current, the phase of 3/1 modes island is changed in the experiments. It is found that the runaway-free disruption happened when the O-point of 3/1 mode island aligns with MGI. However, RE suppression is ineffective when the X-point of the 3/1 mode island is in phase with the MGI. These results imply the significant effect of multi-modes island phase on the RE suppression, which will be helpful for the mitigation of locking mode disruptions.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Nos. 12205122) and the State Key Laboratory of Advanced Electromagnetic Technology (Grant No. AET 2025KF017).

REFERENCES

[1] I. Bandyopadhyay et al. Nuclear Fusion **65**, 103001 (2025)
[2] V. A. Izzo, Physics of Plasmas **24**, 056102 (2017).
[3] C.H. LI et al., Plasma Physics and Controlled Fusion **62**, 095010 (2020).
[4] Varje, Jari et al. arXiv preprint arXiv:1908.02482 (2019).
[5] Hoppe. M. et al. Computer Physics Communications **268**, 108098 (2021).
[6] Konsta Särkimäki et al. Plasma Physics and Controlled Fusion **58**, 125017 (2016).