Experimental study of divertor detachment during RMP ELM control

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Realization of nuclear fusion power faces many difficulties such as improving the high energy confinement and controlling heat loads below an acceptable level on divertors. One significant challenge lies in edge-localized modes (ELM) crash control compatible with detached plasmas to avoid damages to divertor materials including tungsten. Furthermore, evaluating the heat and particle fluxes on the divertor through analysis of experimental data remains crucial for the optimal design of fusion reactors.

To address this concern, various ELM control techniques have been proposed, with resonant magnetic perturbations (RMPs) considered the most promising [1]. However, the compatibility of RMP-induced ELM control with a detachment to manage divertor heat fluxes in high-performance tokamaks like ITER remains uncertain.

In this study, we report on an experimental demonstration of argon-seeded discharges that exhibit a divertor detachment during the ELM control by an ITER-like, three-row RMP configuration in KSTAR [2]. The results suggest that argon seeding may show a potential suitable technique for impurity-seeded detachment in ITER. Furthermore, in the small ELM phase, which is considered a favorable regime for impurity exhaust, an additional reduction in heat and particle fluxes on the targets was observed compared with the ELM suppression phase.

The target discharge was an H-mode plasma with an I_p of 0.5 MA and a B_T of 1.8 T. Neutral beam injection (NBI) was used as a main heating source and a maximum power level was 5 MW. RMP coil currents I_{RMP} started to ramp up at 4.0 s, and reached the maximum current of 2.0 kA/turn on 3-rows with a n = 1, +90° phasing configuration for ELM control. After I_{RMP} reached its maximum value, we injected argon gas at a constant rate from 6.0 s through the gas pipeline connected to the midplane and introduced prefilled and additional fuel gases into the plasma from the midplane and divertor, respectively.

During the application of RMP, complete suppression of ELM was achieved, followed by mitigation until the end of the discharge. Remarkably, during the RMP-driven ELM suppression phase, successful argon-seeded detachment was accomplished. In this phase, the heat flux showed a continuous reduction of 70% compared to the pre-argon seeding case.

The ELM suppression phase abruptly transitioned to the ELM mitigation phase 0.6 s after the argon was injected. During the ELM mitigation phase, the heat flux was reduced by approximately 90% when compared to the pre-argon seeding case.

The degree of detachment (DoD) based on the two-point model was calculated. The DoD increased to levels of approximately 3 and 2.3 for the outer target and inner target cases, respectively. Definitive evidence of detachment was discernible in the 2-D radiation distribution as shown in Figure 1. The concentrated radiation zone shifted gradually from the inner target plate towards the X-point during the argon seeding.

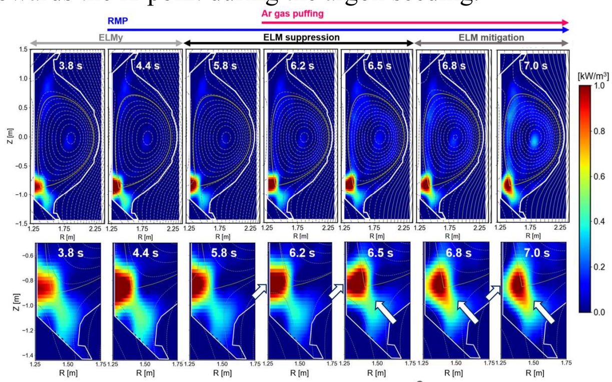

Figure 1 Tangentially reconstructed 2-d radiated power distributions from the imaging bolometer [2].

In addition, experiments using the KAERI plasma beam irradiation facility (KPBIF) have been actively carried out to investigate various plasma-surface interactions by simulating divertor plasmas [4]. Currently, it is operating in continuous-wave mode and it will be upgraded to simulate ELM-like conditions by developing a pulse power supply using capacitor banks.

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References

[1] T.E. Evans *et al.*, Nuclear Fusion **58** (2018) 126010.
[2] H. Shin, J. Hwang, Y. Han, G. Shin, H. Lee, K.-B. Chai and Wonho Choe, Nucl. Fusion **63** (2023) 044003.
[3] H.H. Lee *et al.*, Nucl. Mater. Energy **12** (2017) pp. 541-547.
[4] K.-B. Chai and D. Kwon, Plasma Phys. Control. Fusion **62** (2020) 035007.