DIVERTOR FLUX CONTROL BY RMP ELM SUPPRESSION AND RADIATIVE DIVERTOR OPERATION IN EAST H-MODE WITH TUNGSTEN PLASMA FACING COMPONENTS IN SUPPORT OF ITER NEW RESEARCH PLAN

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Effective divertor flux control has been achieved in EAST H-mode plasmas under high-Z metal (tungsten/ molybdenum) wall conditions, employing plasma-facing components (PFCs) that include tungsten (W) upper and lower divertors, tungsten main limiters, and a molybdenum (Mo) first wall with low boron coverage. To mitigate transient heat loads caused by Type-I Edge Localized Modes (ELMs), n = 2 Resonant Magnetic Perturbations (RMPs) were applied, achieving full ELM suppression. The impact of n = 2 RMP ELM suppression on H-mode energy and particle confinement was limited to less than 10%, while core tungsten concentrations remain effectively controlled. For steady-state divertor heat load reduction, nitrogen (N_2) injection into the divertor during n = 2 RMP operation enabled radiative divertor performance, achieving electron temperatures near the original strike point of the divertor target ($T_{e,div}$) to below 5 eV, approaching a partial detachment state. The $T_{e,div}$ reduction demonstrates dependencies on both the N_2 injection rate and the magnetic field line penetration depth of impurity injection locations relative to the splitting lobes. These results confirm the compatibility of ELM-suppressed H-mode operation with radiative divertor scenarios in a high-Z metal wall environment. These results provide validation for ITER new research plan which has been decided to transfer the first wall material from beryllium to tungsten.

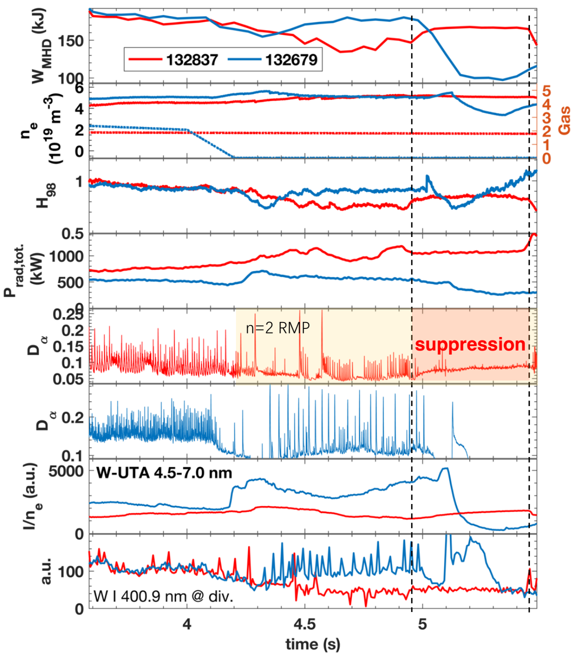

Fig. 1 *Impact of ELM mitigation and ELM suppression with n = 2 RMPs on H-mode performance with high-Z metal wall in EAST.*

One example of the n=2 RMP ELM suppression discharge (#132837) is shown in Fig 1, which compares with a type-I ELMy H-mode shot (#132679) without RMP application. The background plasma scenario in these experiments was a near double-null with dominant lower X-point and with I_p ~ 450 kA and B_t ~ 2.45 T (q_{95} ~ 6). For achieving type-I ELMy H-mode, the central Electron Cyclotron (EC) heating is set to be 1.5MW, and other heating power were provided by Neutral Beam Injection (NBI) of 1.37MW. As the type-I ELMy confinement is highly sensitive with the gap between plasma and the W limiter, the outer mid-plane distance between the separatrix and the limiter is fixed at about 7.5cm. In shot 132837, n = 2 RMP was applied from 4.2 to 5.6s with the upper-lower phase difference of about -150 degree. After RMP application, the ELM mitigation state was reached and the energy confinement (indicated by H_{98} factor here) was reduced stepwise from 0.9 to 0.72. At about 4.9s, there is a non-linear transition from ELM mitigation to suppression state and the H_{98} increased to 0.87, only 3% less than that before RMP application. The particle confinement is not affected by the ELM control. The main impact is on the central ion temperature which decreases when ELM suppression is achieved. During RMP application, there is no obvious accumulation of W in the core and the W level at the divertor plate is reduced. Previous results in EAST show that RMP effects on W reduction are closely related with rotation braking and the impact of RMP induced neoclassical toroidal viscosity (NTV) on low charge states of W is greater than that on high charge states [2]. With a high q_{95} in this shot, according to the MARS-F modelling in advance, the RMP field with higher mode number like n = 4 is not enough for achieving ELM suppression, which is consistent with experimental observation in the experiments that the n = 4 RMP achieves only ELM mitigation with ELM frequency of about 200 Hz. The difference of ELM suppression with such high-Z metal wall between previous RMP ELM suppression achieved in EAST with lithium coating wall condition [3] need further investigation and will be introduced in detail

To explore the compatibility of H-mode confinement, ELM control and the radiative divertor operation, N_2 was injected from the divertor region as impurity during n = 2 RMP application. The background plasma is also with $I_p \sim 450$ kA and $B_t \sim 2.45$ T. The plasma was heated by 2.8 MW EC and 0.6MW NBI with line averaged density $\langle n_e \rangle$ of about 4.2×10^{19} m^{-3}. Different from previous type-I ELM suppression discharges, the background plasmas are a hybrid type-I and type-II ELMs before RMP application. In Fig. 2, shot # 137800 and # 137809 are with 3.5 kA n = 2 RMP application but N_2 injection from O port and H port, respectively. The N_2 injection was from 6.5 s to 8.5 s continuously. The observed electron temperature on the divertor target, which is close to the original striking point, is found to be reduced to below ~ 5 eV as nitrogen and radiative power increase, which indicates a partial detachment state here. No W accumulation is observed during RMP application and N_2 injection. With N_2 injected from different ports, the reduction rate of $T_{e,div}$ of the two discharges were different and found to be dependent on the field penetration depth of the splitting lobes crossing by the gas puffing inlet on the divertor target. More experimental observations and detail analyses will be shown by modeling with 3D plasma boundary model EMC3-EIRENE[4], with plasma responses being included by MARS-F[5].

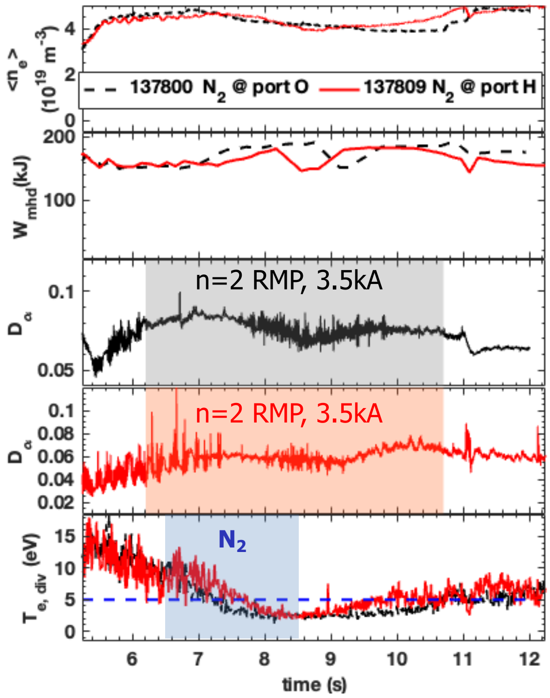

Fig. 2 Comparison of #137800 & # 137809, with N_2 injection from two different ports during RMP application but both achieved $T_{e,div}$ less than 5 eV

These results confirm the compatibility of H-mode operation with tungsten PFCs, particularly under RMP application and radiative divertor operation, which are both essential for ITER divertor heat load control strategy. The field line penetration depth of splitting lobes proximate to the impurity injection location emerges as a critical factor in optimizing the reduction of steady-state divertor flux. These findings advance the understanding of both the physics underlying divertor control in 3D magnetic geometries and the influence of ITER W main wall on the confinement as proposed in the ITER new baseline.

ACKNOWLEDGEMENTS

This work is supported by the National Key R&D Program of China under Grant No. 2024YFE03270600, the Natural Science Foundation of Anhui Province under Grant No. 2208085J39, the National Natural Science Foundation of China under Grant No. 12005261 and No. 11875292. We thank the staff members at EAST (https://cstr.cn/31130.02.EAST), for providing technical support and assistance in data collection and analysis. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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