COUPLED PARTICLE-MHD SIMULATIONS OF INTERATIONS BETWEEN EDGE LOACALIZED MODES AND NEUTRALS AND IMPURITIES USING JOREK CODE

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A coupled particle-MHD model is currently being developed based on the particle extension [1] of JOREK code [2-3] in order to investigate the transport properties of neutrals and impurities, as well as their nonlinear interactions with MHD instabilities. The coupled model treats neutrals and impurities with the full-orbit tracking method, while enabling concurrent simulation of multiple species, such as those originating from gas puffing (e.g., D, Ne, Ar) and plasma-facing component sputtering (e.g., W, C).

In the first application, the impact of recycling process on the edge plasma property and the evolution of edge localized modes (ELMs) are assessed based on an HL-3 [4-5] quiescent H-mode (QH mode) plasma obtained in the previous MHD modelling [5]. The previous MHD modelling employed a simplified recycling model with prescribed instantaneous ionization of the recycled particles, neglecting the neutral transport in the scrape-off layer (SOL). In the coupled modelling, the recycled neutrals are tracked using Monte Carlo particles, self-consistently resolving collisional dynamics including ionization, recombination, and charge-exchange processes. Fig. 1 compares the density and temperature profiles between the coupled particle-MHD and pure MHD simulations, indicating an increase in the edge plasma density accompanied by a decrease in edge plasma temperature due to the involvement of neutral transport.

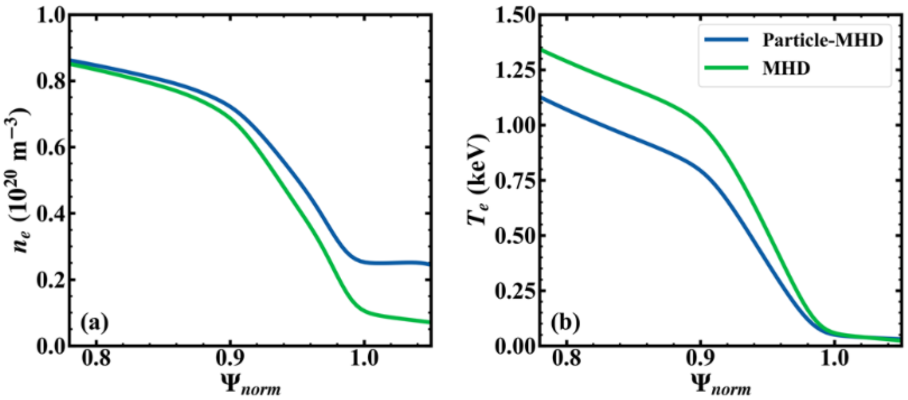

Fig. 1. (a) The toroidal averaged electron density and (b) electron temperature profiles at outer mid-plane in the coupled particle-MHD (blue) and pure MHD (green) simulations.

Furthermore, the impact of recycled neutrals on the evolution of ELMs is investigated in the non-axisymmetric simulations. Ref. [5] reports the achievement of QH mode during the saturated phase via the JOREK nonlinear simulation. The edge harmonic oscillation (EHO) was analysed according to the density fluctuation at the outer mid-plane, exhibiting that the EHO was dominated by the n=2 (f = 15 kHz) and n=3 (f = 22.5 kHz) modes. In the recently performed coupled modelling, a distinct limit cycle oscillation (LCO) phase [7] is observed preceding the EHO onset as shown in Fig. 2, which was not captured in the previous pure MHD simulations. It can be seen that the density gradually decreases during the LCO phase and then fluctuates around a stable level in the EHO phase. In the EHO phase, similar result is obtained in the coupled modelling, where the n=2 and n=3 modes dominate. The identification of LCO phase is attributed to the improved modelling of edge plasma and suggests the enhanced simulating capability of the coupled particle-MHD model.

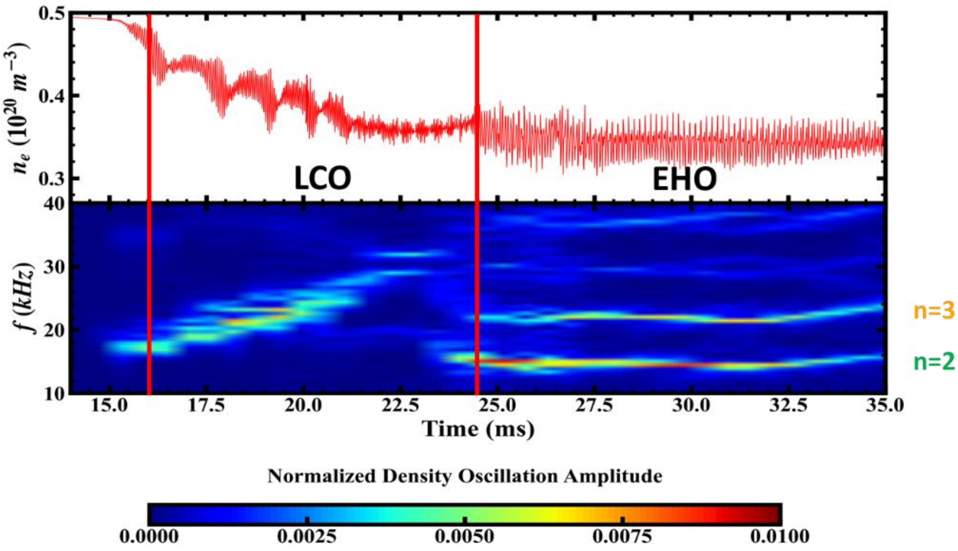

Fig. 2. Density oscillation signal at normalized poloidal flux of 0.95 outer mid-plane during 15~35 ms and its spectrogram. The temporal resolution of the signal is 6.48×10^{-6} s. The peaked oscillation with frequencies of 15 and 22.5 kHz in the EHO phase come from n=2 mode and n=3 mode, respectively.

In summary, the preliminary results presented above reveal the influence of recycled neutrals on edge plasma property and evolution of edge instabilities, while demonstrating the improved simulating capability of the coupled particle-MHD model. In the next step, the impurity effects will be investigated and included in the manuscript, particular focus lying on the interaction between impurity and ELMs, the mitigation of divertor heat loads and ELM-induced target sputtering.

REFERENCES

[1] KORVING, S.Q., HUIJSMANS, G.T.A., PARK, J.-S., LOARTE, A., JOREK TEAM, Development of the neutral model in the nonlinear MHD code JOREK: Application to E × B drifts in ITER PFPO-1 plasmas, Physics of Plasmas 30 4 (2023) 042509.

[2] HOELZL, M. et al., The JOREK non-linear extended MHD code and applications to large-scale instabilities and their control in magnetically confined fusion plasmas, Nucl. Fusion 61 6 (2021) 065001.

[3] HOELZL, M. et al., Non-linear MHD modelling of transients in tokamaks: a review of recent advances with the JOREK code, Nucl. Fusion 64 11 (2024) 112016.

[4] DUAN, X.R. et al., Progress of HL-2A experiments and HL-2M program, Nucl. Fusion 62 4 (2022) 042020.

[5] XUE, L. et al., Integrated plasma scenario analysis for the HL-2M tokamak, Nucl. Fusion 60 1 (2020) 016016.

[6] LIANG, Z. et al., Predictive nonlinear MHD simulations of quiescent H-mode plasma in the HL-3 tokamak, Physics of Plasmas 32 1 (2025) 012502.

[7] MEIER, L. et al., MHD simulations of formation, sustainment and loss of quiescent H-mode in the all-tungsten ASDEX Upgrade, Nucl. Fusion 63 8 (2023) 086026.