Electromagnetic turbulence simulation for quasi-continuous exhaust regime

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Abstract

We present the first turbulence simulations for the quasi-continuous exhaust (QCE) regime using GRILLIX, a global fluid turbulence code with electromagnetic effect [1]. The simulations take the highly-shaped double-null magnetic equilibrium from the ASDEX Upgrade discharge #36165. In our QCE simulation case with a high neutral gas level, we identify a pronounced ballooning mode near the separatrix propagating in the ion drift direction with a scale of $k_{\mathrm{pol}}\rho_s \sim 0.04$ and a frequency of ~ 30 kHz, which all aligns with the experiment measurements [2, 3]. The turbulence diagnostics suggest that the underlying instability is the kinetic ballooning mode (KBM). In a comparative non-QCE case with the same magnetic equilibrium but fewer neutral gas, the developed plasma density at the separatrix $n_{\mathrm{e,sep}}$ is 20% lower, and that separatrix-localized ballooning mode is barely visible. The $n_{\mathrm{e,sep}}$ dependence of that ballooning mode qualitatively coincides with the experimental access condition to QCE [4].

Self-consistent particle and heat turbulent transports are obtained in both cases, leading to corresponding plasma profile evolution. In comparison, the QCE case exhibits significant ExB particle and heat fluxes localized between $\rho_{\mathrm{pol}} = 0.993$ and 0.999, where that ballooning mode resides. In this ρ_{pol} range, the magnitudes of ExB transports are more than 10 times higher in the QCE case than in the non-QCE case, while the diamagnetic and electromagnetic transports stay moderate and behave similarly in both cases. Due to the substantial ExB particle transport in the QCE case, the maximum radial density gradient is flattened by $\sim 16\%$ and slightly shifts inward. Meanwhile, the pedestal width shrinks by $\sim 25\%$ compared to the non-QCE case.

For the first time, from the perspective of non-linear turbulence, our simulations confirm the major hypothesis about QCE: unstable separatrix-localized ballooning modes cause enhanced transport that narrows the pedestal width (thereby avoiding Type-I ELMs). A more detailed analysis of the unstable KBM in QCE will be conducted. The extrapolation to future reactors will be explored.

Keywords— edge plasma, quasi-continuous exhaust, turbulence, ballooning modes

References

[1] Zhang K, Zholobenko W, Stegmeir A, Eder K, Jenko F. Magnetic flutter effect on validated edge turbulence simulations. Nuclear Fusion. 2024;64(3):036016.

[2] Harrer G, Faitsch M, Radovanovic L, Wolfrum E, Albert C, Cathey A, et al. Quasicontinuous exhaust scenario for a fusion reactor: The renaissance of small edge localized modes. Physical Review Letters. 2022;129(16):165001.

[3] Kalis J, Birkenmeier G, Manz P, Eich T, Griener M, Goti R, et al. Experimental characterization of the quasi-coherent mode in EDA H-Mode and QCE scenarios at ASDEX Upgrade. Nuclear Fusion. 2023;64(1):016038.

[4] Faitsch M, Eich T, Harrer G, Wolfrum E, Brida D, David P, et al. Analysis and expansion of the quasi-continuous exhaust (QCE) regime in ASDEX Upgrade. Nuclear Fusion. 2023;63(7):076013.

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