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Impact of nonlinear toroidally axisymmetric flow and field on ELM crash

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ELMs with toroidal axisymmetric (n=0) flow and fields driven by short wave-length instabilities are simulated at the first time by plasma fluid simulation code BOUT++ [1] with an improved Poisson solver and Poisson bracket [2]. In the original BOUT++ code, the n=0 net flow was set to be zero assuming the $\boldsymbol{E}\times\boldsymbol{B}$ flow balanced the ion diamagnetic flow without solving n=0 vorticity equation. Therefore, the zonal flows (the n=0 $\boldsymbol{E}\times\boldsymbol{B}$ flows) driven via the Reynolds stress are not taken into account which plays a role in some cases [3]. In addition, the n=0 magnetic field is also assumed to be negligibly small compared to the equilibrium magnetic field. These limitations are removed here and the impact of these effects is discussed.

Figure 1 summarizes the time evolution of toroidal spectrum of internal energy during ELM crash with n=0 flow and field (hereafter n=0 flow/field) and the time evolution of plasma energy loss released from the plasma edge during ELM crash with/without n=0 flow/field, which are described by a four-field peeling-ballooning model in a shifted circular equilibrium. In this simulation, the ion gyro-viscous force cancels with the Lagrangian derivative of the ion diamagnetic flow [4]. The $\boldsymbol{E}\times\boldsymbol{B}$ flow is generated via the Reynolds stress in the ELM crash with n=0 flow/field while it is set to be zero in the case without n=0 flow/field.

For the ELM crash with n=0 flow/field, the inverse energy cascade from n=20~50 to the n=0 mode is observed during the ELM crash phase t=140t_A~240t_A. The energy loss level with n=0 flow/field saturates after the nonlinear relaxation while the loss without n=0 flow/fields increases gradually without saturation. This difference comes mainly from the existence of the n=0 radial electric field shear (hereafter n=0 E_r shear) driven via the Reynolds stress.

If the n=0 component of vorticity equation and Ohm's law are not solved, the n=0 E_r shear never appears and the pressure filaments can radially spread as shown in the left column of Figure 2. The global structure of the n=0 parallel current is not also observed. On the other hand, the Reynolds stress generates the n=0 E_r shear and the pressure filaments are broken up by it as the right column of Figure 2, which results in the suppression of radial propagation of the pressure filaments. The n=0 parallel current is generated by the n=0 electric field.

In the presentation, we will report the role of n=0 magnetic field for ELM crash as well as a temporal-spatial correlation between the pressure and the Hahm-Burrel $\boldsymbol{E}\times\boldsymbol{B}$ shearing rate [5,6].

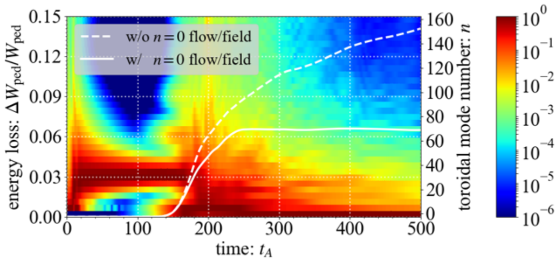

Figure 1: Time evolution of plasma energy loss during ELM crash without (white dashed) and with (white solid) n=0 flow/ field (left y-axis) and time evolution of toroidal spectrum of internal energy during ELM crash with n=0 flow/field (right y-axis).

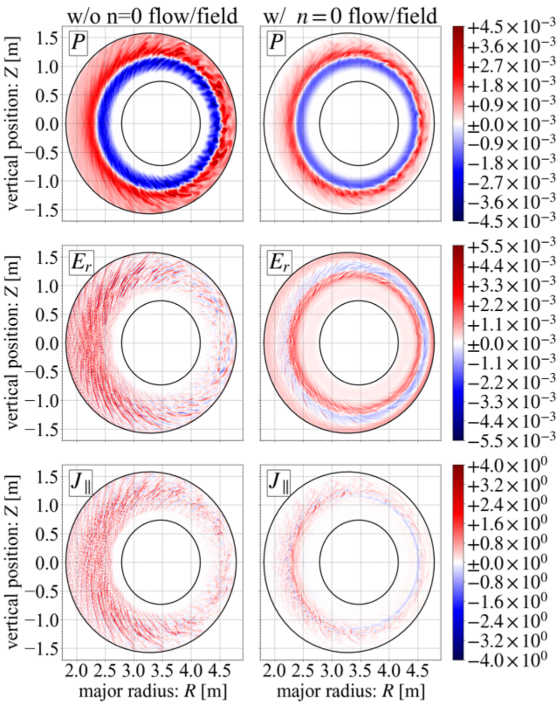

Figure 2: Poloidal slices of pressure P (top), radial electric field E_r (center) and parallel current $J_{//}$ (bottom) after the nonlinear relaxation (t=500t_A) without (left) and with (right) n=0 flow/field respectively.

References

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