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 $E \times B$ flow balanced the ion diamagnetic flow without solving $n=0$ vorticity equation. Therefore, the zonal flows (the $n=0$ $E \times B$ 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 $E \times B$ 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 $t=140\tau_A$--$240\tau_A$. 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 $n=0$, shear) driven via the Reynolds stress.

If the $n=0$ component of vorticity equation and Ohm’s law are not solved, the $n=0$, 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-Burrell $E \times B$ shearing rate [5,6].

References