

§2. Thermal Transport Due to Coexistence of Micro-turbulence with Tearing Modes in Externally Heated Plasma

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Abstract A new three-dimensional numerical simulation of turbulent transport phenomena in an open system controlled by an external heat source and a sink is proposed by virtue of self-consistent calculation of the multi-scale interactions between micro-turbulence and macro-MHD such as tearing modes. External heating is applied to an equilibrium including micro-turbulence, and thermal transport due to the coexistence of micro-turbulence with tearing mode is investigated by numerically solving a reduced set of two-fluid equations. Multi-scale interactions between micro-turbulence and tearing mode play the key role in thermal transport. When tearing mode appears in a quasi-equilibrium including micro-turbulence, the energy spectrum of micro-turbulence is changed so that the energy of the dominant toroidal mode representing micro-turbulence is reduced and the energy of small toroidal mode increases (Fig. 1). At the same time the gradient of ion temperature is reduced and heat flux increases around the magnetic islands due to tearing mode¹⁾ (Fig. 2).

We describe our numerical simulation results in brief. The initial equilibrium is unstable against kinetic ballooning modes and a tearing mode (macro-MHD instability), and the growth rate of former is larger than the latter. The kinetic ballooning modes grow at first, and then a quasi-equilibrium including turbulence is formed for the fixed temperature profile, and it excites $(m, n) = (2, 1)$ mode through nonlinear mode coupling. We remark that this excitation of $(m, n) = (2, 1)$ mode by the turbulence is different from destabilization of tearing mode²⁾. After we obtain the quasi-equilibrium including turbulence we do not fix the temperature profile and add a heat source and a sink that compensate the turbulent heat transport. The quasi-equilibrium including turbulence remains for a while after we add the heat source and sink, then the $(m, n) = (2, 1)$ mode becomes similar to a tearing mode and grows up. Notice that this instability has different features from standard tearing modes such as large growth rate because non-ideal effects due to turbulent mixing of magnetic flux at the resonant surfaces play a role²⁾ and zonal flow affects the growth of tearing modes³⁾. The tearing mode violates magnetic surfaces and produces large-scale magnetic islands, and it affects the micro-turbulence. The magnetic islands reduce the amplitude of dominant Fourier mode of micro-turbulence and increase the energy of low toroidal mode number, and thus the energy spectrum of turbulence is changed as shown in Fig. 1. The reduction of micro-turbulence is due to not only the flattening of

temperature profile around magnetic islands but also the violation of magnetic surfaces. After the appearance of tearing mode the gradient of ion temperature profile is reduced as shown in Fig. 2 and both the heat flux and the thermal diffusion coefficient χ_i increase around the magnetic islands due to the tearing mode. We think that the macro-scale flow of tearing mode cooperates with small scale turbulent flow to mix the plasma and produces large thermal diffusion. The zonal flow profile is altered by the appearance of tearing mode. It seems that the flow shear becomes strong around the magnetic island due to the tearing mode.

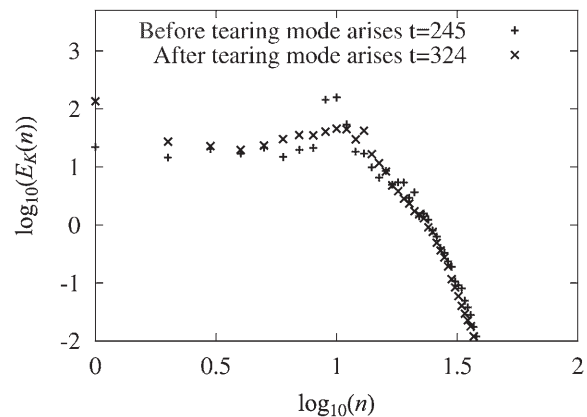


Fig. 1: Energy spectrum of kinetic energy for toroidal mode number n before and after tearing mode appears. The dominant mode of micro-turbulence, $n = 9$ and 10 decreases after the appearance of tearing mode.

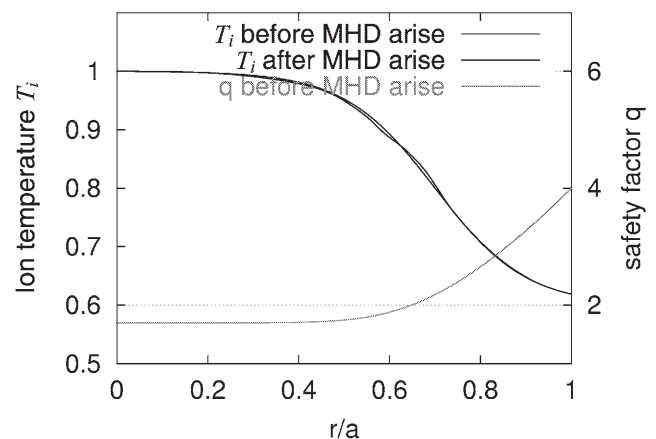


Fig. 2: Ion temperature profile averaged over poloidal and toroidal angles. Its gradient is reduced around magnetic islands that appears at rational surface of $q = 2$, $r_s/\tilde{a} = 0.65$ after the growth of tearing mode (macro-MHD).

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- 2) A. Ishizawa and N. Nakajima, AIP Conference Proceedings **1069** 110 (2008).
- 3) A. Ishizawa and N. Nakajima, Physics of Plasmas, **15**, 084504 (2008).