§23. Nonlinear Simulation of the Current-Diffusive Interchange Mode

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Anomalous transport is the dominant mechanism in determining the plasma confinement in toroidal helical devices. Recently, we have presented the anomalous transport theory based on the self-sustained turbulence approach [1]. The impact of the geometry was clarified. The nonlinear numerical simulation is performed to confirm this theoretical framework [2].

We study the electrostatic interchange mode in a slab plasma (x- and z-axes are taken in the direction of the pressure gradient and main magnetic field, respectively). We focus to investigate the nonlinear mechanism on electrons. The reduced set of equations is employed as

$$\partial p/\partial t + [\phi, p] + \nabla_y \phi = \chi_c \Delta_\perp p$$

$$\partial \nabla_\perp^2 \phi/\partial t + [\phi, \nabla_\perp^2 \phi] = \nabla_\parallel j - \Omega \nabla_y p + \mu_c \nabla_\perp^4 \phi.$$

The Ohm's law which we use is given by

$$\partial j/\partial t + [\phi, j] = -\nabla_\parallel \phi + \lambda_c \Delta_\perp j$$

In the simulation study, we normalize the length and time by c/ω_p and τ_{Ap}, respectively, operator $\nabla_y = \partial/\partial y$ denotes the influence of the equilibrium gradient in the x-direction, Ω is the drive by curvature, and [,] is the Poisson bracket. The terms λ_c, μ_c and χ_c denote the transport coefficients due to the Coulomb collisions. (Here we regard them as constant numbers.) Simulation is done for the fixed background pressure gradient. Range in the x-direction is L, and M Fourier modes in k_y are kept. Parameters L=80 (300 grids) and M=64 (k_y^{min}= 10/64 and k_y^{max}=10) are usually taken for the two-dimensional simulation.

Figure 1 shows the time evolution of the perturbed pressure $W_E = \langle p^2 \rangle$, for the case of $\lambda_c=0.01$, $\langle p^2 \rangle \equiv (2L)^{-1}\int_0^L dx\, M^{-1} \sum | p(x,k_y)|^2$. The case of the linear Ohm's law (i.e., $[\phi,j]$ term is neglected in Ohm's law) is also shown by the dotted line. (Other parameters: Ω=0.5, s=0.5, $\chi_c = \mu_c = 0.2$.) The linear growth of the mode corresponds to the electron-inertial interchange instability. If the convective nonlinearity works in the Ohm's law, the growth rate starts to increase when the fluctuation level exceeds a threshold value. This level of threshold amplitude coincides with the theoretical prediction of the nonlinear instabilities [1]. (The mode shows a simple nonlinear saturation when the linearlized Ohm's law is employed.) The nonlinear destabilization is confirmed.

The saturation stage is also investigated. Three cases are compared: (a) nonlinear Ohm's law with $\lambda_c = 0.01$, (b) linear Ohm's law with λ_c=0, and (c) nonlinear Ohm's law with λ_c= 0.2. In the time asymptotic limit, the saturation is realized. The saturation level for nonlinear instability, (a) and (c), is much higher than the case of the linear Ohm's law (b). It is confirmed that the convective nonlinearity in the electron dynamics gives rise to the nonlinear acceleration of the growth rate and the enhanced saturation level. We compared the cases (a) and (c), the latter of which has larger linear growth rate. We see that the enhanced saturation level is not influenced by the linear growth rate much. Through these numerical simulations, the theoretical model of the self-sustained turbulence is confirmed.

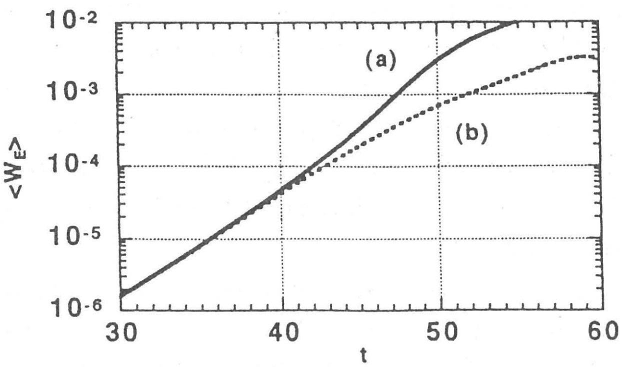

Figure 1 Temporal evolution of perturbed pressure energy, showing the nonlinear growth. Nonlinear Ohm's law (solid line), and linearlized Ohm's law (dashed line) are used.

References

1) ITOH, K., et al.: Phys. Rev. Lett. **69** (1992) 1050, ITOH, K., et al.: Plasma Phys. Contr. Fusion **36** (1994) 279.
2) YAGI, M., et al: paper in preparation.