§27. Self-Sustained Turbulence and L-Mode Confinement in Toroidal Plasmas

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We have recently proposed a new theoretical method to analyze the anomalous transport phenomena in magnetic confinement devices [1]. In this new theoretical approach, the instabilities are caused by the anomalous transport itself. Hence the fluctuations and transport coefficients are sustaining each other, under the condition of the given gradients of equilibrium plasma parameters.

The influence of parallel compressibility is studied, which was neglected in previous work, on the self-sustained turbulence. It is shown that the effect of this new term is small and does not change the previous conclusion qualitatively. The ion viscosity for perpendicular and parallel moments, the electron viscosity and the energy diffusion coefficients are obtained. These four quantities are found to be of the same order of magnitude. The relative ratio between them is discussed.

The reduced set of equations for the electrostatic potential \( \phi \), pressure \( p \), current \( J \) and parallel velocity \( v \) are employed (See [2]) as

\[
\frac{\partial \nabla^2 \phi}{\partial t} + [\phi, \nabla^2 \phi] = \nabla \cdot J + (2\xi \cdot \xi') \nabla p + \mu_e \nabla^4 \phi
\]

\[
\frac{\partial v}{\partial t} = - \nabla \phi - \frac{1}{\xi} \left( \frac{\partial J}{\partial t} + [\phi, J] \right) - \eta J + \lambda_e \nabla^2 J
\]

\[
\frac{\partial p}{\partial t} + [\phi, p] = - \beta \nabla V \cdot v + \chi_e \nabla^2 p
\]

\[
\frac{\partial \nabla \cdot \nabla \phi}{\partial t} + [\phi, \nabla^2 \phi] = - \nabla p + \mu_e \nabla^2 \nabla \phi
\]

constitute the set of basic equations. In these equations, \( \Omega \) is the average curvature of the magnetic field, \( \Psi \) is the vector potential, \( 1/\xi \) denotes the finite electron inertia, \( 1/\xi = (\delta/a)^2 \), \( \eta \) is the classical resistivity, and \( \beta \) is the ratio of the plasma pressure to the magnetic pressure.

The transport coefficients, sum of the turbulent transport and collisional transport, \( \mu_{\perp}, \lambda_e, \chi_e, \mu_\perp e \), are obtained by the renormalization [3].

The renormalized equations are given as a linear form for the dressed test wave with diffusion coefficients \( (\mu, \lambda, \chi, \mu_\perp) \). Eliminating \( J \) and \( v \) from the set of equations, we have

\[
k_{\parallel} \frac{k_{\parallel}^2}{\gamma (1 + \xi^{-1} k_{\parallel}^2) + \lambda k_{\perp}^4} \phi + (\gamma + \mu_{\perp} k_{\parallel}^2) k_{\perp}^2 \phi - i \Delta_k \phi = 0
\]

\[
(\gamma + \lambda k_{\parallel}^2 + \beta k_{\parallel} k_{\perp} + \frac{1}{\gamma + \mu_{\perp} k_{\parallel}^2}) \phi - i G_k \phi = 0
\]

(The tilde denotes the dressed test wave in this set of equation.) The term which is proportional to \( \beta \) (the last term in the bracket of the left hand side) denotes the effect of the parallel compressibility. If this term is neglected, the result in the previous article is recovered.

The effect of the parallel compressibility is treated perturbatively. It is shown a posteriori that the correction is of a higher order in the inverse aspect ratio, and this expansion is validated. Expanding the pressure perturbation with respect to \( \phi \), \( p \) is given in terms of \( \phi \) as

\[
\beta = \frac{i G_k}{\gamma + \chi k_{\parallel}^2} \left( \frac{1}{1 - \beta k_{\parallel} + \frac{1}{\gamma + \mu_{\perp} k_{\parallel}^2}} \right) \phi
\]

Substituting this expression, we have

\[
k_{\parallel} \frac{k_{\parallel}^2}{\gamma (1 + \xi^{-1} k_{\parallel}^2) + \lambda k_{\perp}^4} \phi + (\gamma + \mu_{\perp} k_{\parallel}^2) k_{\perp}^2 \phi
\]

\[= - \frac{k_{\parallel}^2 D_0}{\gamma + \chi k_{\parallel}^2} \left( \frac{1}{1 - \beta k_{\parallel} + \frac{1}{\gamma + \mu_{\perp} k_{\parallel}^2}} \right) \phi = 0
\]

The term \( D_0 \) denotes the driving term of the interchange instability, \( D_0 = -\Omega e^{-2} dp/d\tau \). This equation is the eigenvalue equation for the dressed test wave. It is found that, compared to the case of the three field model, the driving term is decreased due to the influence of the parallel compressibility. If the term of \( O(\beta) \) is neglected, the model equation in the preceding article [1] is recovered.

References