§28. Self-Sustained Magnetic Braiding in Toroidal Plasmas

Itoh, K., Fukuyama, A. (Okayama Univ.)

Itoh, S.-I. (Kyushu Univ.)

Yagi, M. (Kyushu Univ.)

The method of self-sustained turbulence [1] is applied to the magnetic braiding in toroidal plasmas. It is found that, if the pressure gradient exceeds a certain threshold value, the self-sustainment of the magnetic braiding occurs, causing higher thermal conductivity. Taking the interchange mode turbulence as an example, we obtain the analytical formula of χ , the magnetic perturbation amplitude and the threshold pressure gradient. The dependence of χ on the pressure gradient and the magnetic structure is clarified. It is found that, when the pressure gradient exceeds the threshold, χ_e increases by the factor about m_i/m_e (ion-to electron mass ratio). Even the ion thermal conductivity χ_i is enhanced by the factor $\sqrt{m_i/m_e}$. The magnetic fluctuations are found to have the nature of the cusp-type catastrophe. The explosive burst occurs at the critical point. This new finding provides the understanding of a path for the high- β disruption (β : ratio of plasma pressure to magnetic pressure). The threshold pressure for the catastrophe is compared to the stability boundary for the linear magnetohydrodynamic (MHD) mode.

We study the high-aspect-ratio, toroidal helical plasma with magnetic hill and strong magnetic shear. By use of the similar analytic method shown in the previous article, we have the thermal conductivity in the limit of strong magnetic stochasticity as

$$\chi_i = \chi_E \left(\frac{G_{\alpha} + G_{0e} \sqrt{m_e T_i / m_i T_e}}{G_{\alpha} + G_{0e}} \right)^{3/2} \sqrt{\frac{m_i T_e}{m_e T_i}}$$

where G_0 is the product of the bad curvature and pressure gradient ($G_0 = \Omega' \epsilon^{-2} \beta'$), $\chi_e = \sqrt{m_i/m_e} \chi_i$ and χ_E is the one in the L-mode transport theory [1].

The critical condition for the occurrence of the magnetic braiding is derived by studying the overlapping condition for the microscopic magnetic islands as

$$G_{0e} + G_{0i} > G_c = H^* b^* \left(\frac{k_{\perp}}{k_{\theta}} \right)^4 s \approx 2.8 s.$$

The level of magnetic perturbation is explicitly derived from this result. We have the amplitude in the large pressure gradient limit as

$$\frac{\tilde{B}_r}{B} \approx \frac{b_*^{1/2}}{H^* s} \frac{c}{a \omega_p} \frac{\epsilon v_A}{v_{Ti}} \left(\frac{m_i T_e}{m_e T_i} \right)^{1/4} \left(G_{0i} + G_{0e} \sqrt{\frac{m_e T_i}{m_i T_e}} \right)$$

When the gradient parameter

$(G_{0i} + G_{0e} \sqrt{m_e T_i / m_i T_e})$ becomes small, the perturbation amplitude decreases. The magnetic braiding disappears if $(G_{0i} + G_{0e} \sqrt{m_e T_i / m_i T_e})$ goes below a critical parameter

$$G_1 \approx 9 \beta_i.$$

These results show that there is a new type of the bifurcation in the transport coefficient. At a certain pressure gradient, the transport catastrophe occurs. Figure 1 summarizes this cusp type bifurcation at the critical pressure gradient.

Fig.1 The normalized fluctuation amplitude $\tilde{A}$, $\tilde{A} = (\tilde{B}_r/B_0)(a\omega_p/c\epsilon)$, as a function of total pressure gradient parameter G_0 , $G_0 = G_{0e} + G_{0i}$. The lower line (denoted by L) indicates the level in the L-mode confinement. The upper part (denoted by M) shows the level in the magnetic stochastic turbulence.

Reference

- 1) Itoh K, Itoh S-I and Fukuyama A 1992 Phys. Rev. Lett. **69** 1050,