§23. Self-sustained Turbulence and H-mode Confinement in Toroidal Plasmas

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The equation for the dressed test mode for the nonlinear ballooning mode turbulence in the presence of the radial electric field has been derived [1] as

$$d^2p/d\eta^2 + (\alpha\Lambda/K)\{1-(1/2+\alpha-s)\eta^2\}p - M\Lambda[1+3(s-\alpha)^2\eta^2]\,p + L_1 p = 0$$

$$L_1 p \equiv \omega_{E1}\left[KF^{-1}\, d^3p/d\eta^3 - \Lambda(1+M/K)F^2 dp/d\eta\right]$$

In this equation, normalization is: $r/a \to \hat{r}$, $t/\tau_{Ap} \to \hat{t}$, $\chi\tau_{Ap}/a^2 \to \hat{\chi}$, $\mu\tau_{Ap}/a^2 \to \hat{\mu}$, $\tau_{Ap}/\mu_0\sigma_c a^2 \to 1/\hat{\sigma}$, $\lambda\tau_{Ap}/\mu_0 a^4 \to \hat{\lambda}$, $\gamma\tau_{Ap} \to \hat{\gamma}$. We employ the notation $\tau_{Ap} \equiv a\sqrt{\mu_0 m_i n_i}/B_p$, $\Lambda = \hat{\lambda}n^4q^4$, $K = \hat{\chi}n^2q^2$, $M = \hat{\mu}n^2q^2$, $F = 1 + (s\eta - \alpha\sin\eta)^2$, $s = r(dq/dr)/q$, $\omega_{E1} = \tau_{Ap}(dE_r/d\hat{r})(srB)^{-1}$ and $\alpha = -q^2R\beta'$. Other notation is standard.

The eigenfunction is written as

$$p(y) = u_0 + \sum_{n=1} a_n u_n$$

where the function u_n is explicitly given as $u_n = H_n(y)\exp(-y^2/4)$ and $H_n(y)$ is the n-th order Hermite function. The odd and even parity modes are mixed by the operator L_1 when $\omega_{E1} \neq 0$. The normalized eigenvalue is calculated by

$$\Omega = \frac{1}{2} + \sum_{n=1}^{\infty} \frac{1}{n}\langle 0|L_1|n\rangle\langle n|L_1|0\rangle.$$

(In the previous work [1], only neighbouring terms were kept.) The turbulent transport coefficient is given as

$$\hat{\chi}_H = \frac{\hat{\chi}_L}{1 + G_1\,\omega_{E1}^2}$$

$$G_1 = 8\alpha(1+2\alpha-2s)\left\{2 + \frac{6(s-\alpha)^2}{1+2(\alpha-s)}\right\}^{-1} \times\left[\left\{\frac{3}{8}(1-(s-\alpha)^2) + \frac{2(1+6(s-\alpha)^2)}{4\alpha}\right\}^2 + \frac{1}{2}\left\{\frac{1-5(s-\alpha)^2}{4} - \frac{2(s-\alpha)^2}{\alpha}\right\}^2 + \frac{3}{8}\right]$$

The contour lines of $\hat{\chi}_H$ are illustrated in Fig.1 on the $\alpha - \omega_{E1}$ plane. The correction appears in the numerical coefficient G_1.

The cross-field momentum flux can be calculated by the relation

$$P_{\theta,r} = -\mu_H \nabla V_\theta .$$

Normalized momentum flux is given as $\hat{P}_{\theta,r} = \hat{\mu}_H\omega_{E1}$, and the normalized velocity gradient is expressed by ω_{E1}. Figure 2 illustrates $\hat{P}_{\theta,r}$ as a function of ω_{E1}. Viscosity is calculated and is close to $\hat{\chi}_H$. It is shown that the radial momentum flux is a decreasing function of the velocity shear in the high rotation shear limit. This indicates that, for a fixed momentum flux, two solutions of the rotation shear are available. This provides a basis for the bifurcation in the radial electric field structure in the H-mode modelling .

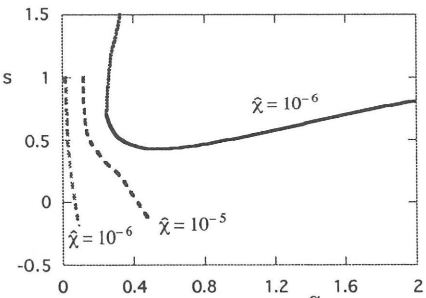

Fig.1 Contour plot of the normalized thermal conductivity as a function of (α, ω_{E1}).

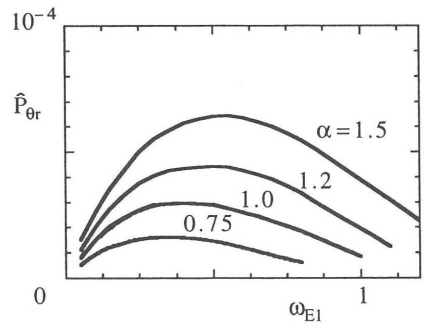

Fig.2 Anomalous cross-field momentum flux $\hat{P}_{\theta r}$ as a function of the velocity gradient ω_{E1}.

Reference

[1] Itoh S-I, Itoh K, Fukuyama A and Yagi M 1994 *Phys. Rev. Lett.* **72** 1200