§20. Role of Flow Shear and Magnetic Shear for Interchange Instabilities and Improved Confinement

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Even for the well-known MHD instability such as the interchange mode, there appears an interesting situation when both the flow shear and magnetic shear are included simultaneously in the stability analysis. Several years ago a sufficient stability criterion for the ideal interchange mode was derived for a cylindrical plasma with a magnetic shear in the presence of a poloidal shear flow [1]. The radially localized mode in the neighborhood of the mode resonant surface $r = r_0$ is described by

$$\frac{d^2\tilde{\phi}}{dx^2} + \left\{ \frac{k_{\theta 0}^2 P_0' \Omega'}{[(\omega_E')^2 - (k_{||}')^2]x^2} - k_{\theta 0}^2 \right\} \tilde{\phi} = 0 \,, \quad (1)$$

where $k_{\theta 0} = m/r_0$, $P_0' = dP_0/dr|_{r=r_0}$, $\Omega' = d\Omega/dr|_{r=r_0}$, $x = r - r_0$, $k_{||} = k_{||}'x$, $\omega - \omega_E = -\omega_E'|_{r=r_0}x$ and $k_{||}' = m\imath'|_{r=r_0}$. Here $\imath(r)$ is a profile of rotational transform and Ω is a potential function of average magnetic curvature in stellarator / heliotron devices. The poloidal rotation frequency is given by $\omega_E = k_\theta v_E/v_{pA} = (m/r)(d\Phi_0/dr)$, where Φ_0 is an equilibrium electric potential function. Here $v_E(v_{pA})$ is an $E \times B$ drift (a poloidal Alfven) velocity. By assuming $\tilde{\phi} \propto x^\nu$ for the solution of eq.(1), the necessary stability condition becomes,

$$-\frac{k_{\theta 0}^2 P_0' \Omega'}{(k_{||}')^2[1 - (\omega_E'/k_{||}')^2]} < (1/4) \,, \qquad (2)$$

which corresponds to a non-oscillatory solution. From the stability criterion (2), the well-known Suydam criterion is obtained in the case of $\omega_E' = 0$ or by neglecting the poloidal shear flow.

The stability criterion suggests several points for the interaction between the magnetic shear shown by $k_{||}'$ and the poloidal velocity shear shown by ω_E'.

1) When the magnetic shear is zero or very weak,

$$(k_{\theta 0}^2 P_0' \Omega'/(\omega_E')^2) < (1/4) \,, \qquad (3)$$

which means that the interchange mode is stable for $\Omega' > 0$ (magnetic hill) since $P_0' < 0$. This is different from the speculation for the case of $\omega_E' = 0$.

2) When $\Omega' < 0$ (magnetic well), the interchange mode becomes unstable particularly in the case of weak poloidal velocity shear. This is also different from the speculation for the case of $\omega_E' = 0$.

3) It is also well-known that the Kelvin-Helmholtz mode is destabilized by the velocity shear, and the magnetic shear has a stabilizing effect on the K-H mode. Thus, for the weak magnetic shear, it will be difficult to obtain the large velocity shear and the stability against the interchange mode becomes worse in the case of magnetic well.

4) For the finite magnetic shear case, the stability limit decreases compared to the Suydam limit given by the relation (3) in the case of $|k_{||}'| > |\omega_E|$. The destabilizing mechanism is the same as for the K-H mode, and magnetic well has a stabilizing effect on the interchange mode. However, when $|k_{||}'| < |\omega_E'|$, the magnetic hill becomes favorable.

Reference

1) Watanabe, K., Sugama, H. and Wakatani, M., Nucl. Fusion **32** (1992) 1647