§29. Density Limit Oscillation in Helical Plasmas

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Density limit is known to be induced by the radiation loss. The radiation loss is modelled in a form of

$$P_{rad} = n^2 \left(\frac{n_I}{n}\right) \xi T^{-\gamma} V \qquad (1)$$

Based on these simplifying assumptions, we solve the coupled system of density and temperature. The sudden loss of density is predicted to occur. When the radiation instability collapse continues and the temperature becomes lower than the critical value, the symmetry-breaking perturbations of temperature and potential on the magnetic surface become unstable. By the growth of these perturbations, the rapid loss takes place. The details are discussed in the Appendix. The critical condition for this instability is given in terms of the density and temperature as:

$$T n^{-y} \le \zeta \equiv \left(\frac{q^2 R^2}{3\chi_0} \frac{n_I}{n_e} \xi\right)^{1/(\gamma+3.5)}$$

and

$$y = \frac{2}{\gamma + 3.5} \qquad (2)$$

When this instability occurs, the rapid plasma loss happens as

$$\frac{d}{dt} n = -\frac{1}{\tau_M} n \qquad (3)$$

where the right hand side represents the loss induced by this instability. An estimate of the loss rate of plasma density can be made as

$$\frac{1}{\tau_M} \sim \frac{s+\gamma}{C_a \tau_{rad}} \left(1 - \left(\frac{T n^{-y}}{\zeta}\right)^{\gamma+3.5}\right) \qquad (4)$$

where s denotes the response of density to the inhomogeneous temperature perturbation, the coefficient $k_\perp^2 a^2 \sim C_a$ which is of the order unity, and

$$\frac{1}{\tau_{rad}} \equiv \frac{1}{3}\left(\frac{n_I}{n_e}\right) \xi n T_0^{-\gamma-1} \qquad (5)$$

By using the time rate of change τ_{rad} the temperature evolution is rewritten as

$$\frac{d}{dt}\frac{T}{T_0} = \frac{1}{\tau_{rad}}\left(\frac{n_0}{n} - \left(\frac{T_0}{T}\right)^{\gamma} \frac{n}{n_0}\right) \qquad (6)$$

Equations (3) and (6) are solved for the linearlized variables as

$$T = T_0(1 + \delta T) \qquad (7a)$$

and

$$n = n_0(1 + \delta n)\,. \qquad (7b)$$

where (n_0, T_0) is a fixed point of Eqs.(3) and (6). From Eqs.(3) and (6), we find that oscillatory solution exists if the condition

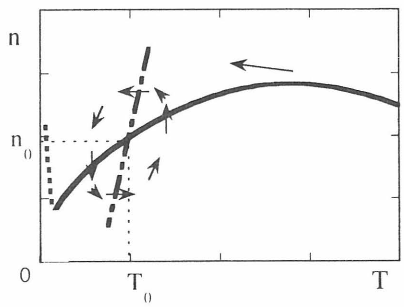
$$\frac{8(s+\gamma)(\gamma+3.5)}{C_a} > \left(\gamma + \frac{2(s+\gamma)}{C_a}\right)^2 \qquad (8)$$

holds. An unstable oscillation exists if

$$\gamma > \frac{2(s+\gamma)}{C_a} \qquad (9)$$

is satisfied together with Eq.(8). In order to satisfy the instability condition, Eq.(9), $C_a > 2$ is the necessary condition.

Figure illustrates the self-generated oscillations. Solid line indicates the condition that the right hand side of Eq.(6) vanishes. Dashed line indicates Eq.(2). If Eqs.(8) and (9) are satisfied, the cross point of these two lines is an unstable fixed point, and limit cycle solution is possible.



Evolution of temperature and density when density limit is reached. A case of limit cycle oscillation is shown.