§29. On the Beta-Limit in Toroidal Plasmas

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The problem of the beta limit in toroidal plasma is still one of the major problem in the confinement theory. This is because, although abundant calculation has been performed in the linear stability theory, this linear theory itself is insufficient in understanding the beta limit in toroidal plasmas. In experiments, the abrupt burst of magnetic perturbations has been observed, which has shown a contrast to the linear theory. The detailed and precise calculation of the linear stability boundary has not been sufficient to predict the beta limit in toroidal plasmas.

The method of self-sustained turbulence was applied to the self-sustained magnetic braiding [1]. The result predicted the Riemann-Hugoniot catastrophe. This theory has predicted the sudden catastrophe at a certain pressure gradient, which would be eventually the beta-limit of the toroidal plasma. This theory also provides a picture of the experimental abruptness in the increment of the magnetic perturbation, which has been observed at the achievable beat limit. This sudden crash has long been a mystery, since majority for the beta-limit theory has been developed on the linear stability.

There are two singular points, i.e., the transition from the L-mode to the M-mode (i.e., magnetic braiding mode), $G_0 = G_c$ and that from the M-mode to the L-mode.(G_0 being the normalized pressure gradient coupled with the bad curvature). At the transition point, (i.e., $G_0 = G_c$), the explosive growth of the longer-wave-length modes happens and the sudden increment of the amplitude occurs. This is a path of the high-β disruption. At the left transition point ($G_0 = G_1$), the sudden termination of the fluctuations are predicted.

The condition for the generation of magnetic braiding is calculated as

$$\left| R \frac{d\beta}{dr} \right| > \frac{2.8}{R\kappa} s \qquad (1)$$

where κ is the magnetic curvature dlnB/dr, and the normalization is not employed. The simple estimate of the linear MHD stability criterion was given as [2]

$$\left| R \frac{d\beta}{dr} \right| > \frac{1}{4r\kappa} s^2 \qquad (2)$$

It would be worthwhile to compare the prediction of the transport catastrophe and the usual linear calculation.

First, we observe some similarity in between them. The criterion for the high-β catastrophe, Eq.(1), is near the stability boundary for the ideal linear MHD mode (2): the higher the magnetic shear, the larger the critical beta. Our theory predicts that the critical beta is close to the linear stability criterion against the ideal MHD mode.

At the same time, we notice a difference as well. A simple estimate of the linear theory has shown the dependence of s^2, while the new theory of the transport catastrophe predicts the linear dependence on s. This will give new impact in evaluating the system from the view point of the achievable beta value. In real situations the change of the magnetic shear cannot be made without changing other parameters such as the magnetic hill or the ripple ratio. The choice of the system often be in front of the necessary compromise in between different request (e.g., beta limit, transport, particle trapping, etc.). In performing this kind of the compromise, the difference in the dependence on s will lead a change in the design principle.

References

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