Shear-flow effects in open traps

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Understanding properties of plasma turbulence in presence of sheared plasma flows is extremely important for control of the turbulent transport. For plasma confinement in tokamaks this topic is studied extensively as a part of the L-H transition problem. Meanwhile, the physics of turbulence in open traps is much the same as in tokamaks, though with notable absence of the magnetic shear effects, while the flow control is more easy. Thus, an off-axis RF heating of electrons in the Gamma-10 ambipolar trap (Tsukuba, Japan) is causing an increase of the ambipolar potential in the heated layer and generates the sheared azimuthal flow. The Gamma-10 group claims that the transverse drift transport is then suppressed and the plasma parameters are improved significantly. In the axially symmetric gas-dynamic trap (the GDT, Novosibirsk, Russia) the external potentials are applied to limiters and concentric sections of the end walls. As a result, the trap now routinely operates in regimes with an average magnetic hill (which should be strongly MHD-unstable to interchange modes) with negligible transverse losses even at $\beta \sim 60\%$. It means that the sheared flows can suppress not just the transport by drift-modes, but the much stronger interchange convection as well. The fact greatly improves prospects for confinement in axially symmetric mirror traps.

Two new ideas in the theory of plasma turbulence with a sheared flow will be presented. The first one corrects the common view of the linear stability theory. This view is based on the theorem, that there are no linearly unstable interchange modes except those associated either with some extrema of the flow profile, such as inflection points, or with the plasma boundaries[1]. It is often concluded that thus the interchange can be suppressed by specifically profiling the flow, as to eliminate the inflection points, etc. It would be strange, since even a vanishingly weak flow would then suppress such robust instability as an interchange. It will be shown that though the theorem is true, it concerns the exponentially growing eigenmodes only. The initial problem can be solved analytically in some model cases. It exhibits growing pseudo-wave perturbations. Their growth rate changes from the unmodified exponential to a power law with time, while the radial wavenumber increases. The linear stability condition for these modes is exactly the same as without the flow. It means that there is no reason to believe that by profiling the flow one can achieve linear stability for the interchange if it is otherwise unstable. However, due to ballistic behavior of such modes (increase of their radial wavenumber with time), the turbulent convective transport is affected significantly.

Another idea concerns the interpretation of the improved plasma confinement in the GDT. It can be explained as follows: let the hot core plasma reside inside of a 2D vortex. It will not convect to the wall if the vortex flow lines are closed and more-or-less concentric, and if the vortex itself is somehow tied to its place. Both conditions can be satisfied if the vortex flow is supported by the stationary wall potentials and the saturated amplitude of the interchange is smaller than that of the vortex. The theory of the vortex transport barrier to be presented is supported by computer simulations and experimental data.

References

[1] A.V. Timofeev, in Reviews of Plasma Physics, v. 17, ed. B.B. Kadomtsev (New York: Consultants Bureau, 1992) p. 193.