The shearing modes approach to the gyrokinetic theory

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- Research frontier

In spite of the great progress in the gyrokinetic simulations of the tokamak turbulence, there still remain key problems in the application of the gyrokinetic approach to the investigation of the stability and turbulence of the sheared ExB flows and related phenomena such as L-H transition, reduction of anomalous transport, development of the transport barriers and generation of ELMs. One of the most challenging problem in the theory of the tokamak plasma shearing flows is the development of the appropriate analytical methods for the investigations of the temporal evolution of the instabilities and turbulence.

The existing analytical studies of the instabilities and turbulence in the tokamak sheared flows are based, as a rule, on the traditional so-called normal modes (or modal) approach which employs the spectral expansion in time which follows the eigenvalue analysis. However, it is well known that the eigenfunctions corresponding to their eigenvalues are not mutually orthogonal for the fluid and plasma shearing flows and experience strong interference [1]. Therefore, it is inappropriate to analyse the shearing flow stability, especially the process of the damping of the instabilities by shearing flows by considering the eigenvalues alone. The physical content of that mathematical effect is discovered easily by the analysis of the temporal evolution of the perturbations in sheared flows, using the wave number-time variables instead of the traditionally applied wave number-frequency variables. It was obtained in Refs. 2–4, that the wave number components k_y (along the direction of the flow across the magnetic field) and k_x (along the velocity gradient) of the the initial perturbation are evolved in time due to the continuous distortion in the sheared flows in such a way that $K_x = k_x + k_y V_0' t = const$, i.e. leaves unchanged with time. The effect of the velocity shear, V_0', on the evolution of the perturbation becomes pronounced, when during the time of the order of the inverse modal growth rate $\gamma(\mathbf{k})$ the time dependent part (so called non-modal part) becomes dominant, i.e. when $V_0' > \gamma$, that is the famous "quench rule", discovered in the gyrokinetic turbulence simulations [5, 6]. We proved that it is the necessary condition for the observed quenching the turbulence [2-4], but is not a sufficient one [4]. The second result of principal importance which follows from the above integral was derived in Refs. 2–4. It was proved that the perpendicular flow shear in Vlasov equation reveals in the shear-induced time dependence of the finite-Larmor-radius effect and this effect is the basic linear mechanism of the influence of perpendicular shearing flow on waves and instabilities. Because of this, the drift kinetic equation does not include the effects of

the shearing flow during the instability evolution. The effect of the velocity shear reveals in time $t > (V_0')^{-1}$, at which the wave number is time dependent and applications of the dispersion equations methodology is dubious. That dominant effect of the modes shearing, however, usually completely ignored in the gyrokinetic theory and simulations.

- Approach to advancing the frontier

The development of the analytical, computational approaches and software tools for the simulation of the turbulence induced by plasma shear flows which are based on the shearing modes methodology, is of principal importance for the contemporary tokamak theory. The developed theory should be capable of treating the perturbations with wide range of spatial scales: from low k_y ($k_y\rho_i < 1$) to intermediate k_y ($k_y\rho_i \sim 1$) and high k_y ($k_y\rho_i > 1$), where ρ_i is the ion gyroradius. The need consists not only of the necessity to include multiple instabilities which are responsible for transport in different channels at different scales [6], but also of the secular temporal growth due to shear flow of the wave number component along the velocity gradient.

- Impact on plasma science and potential societal benefits

The availability of the analytical theory and simulation codes based on the shearing modes approach is very important for the investigations of the turbulent shearing plasma flows. It will enable us to understand the numerous mysterious phenomena detected in experiments and simulations of the tokamak plasmas.

1. L. N. Trefethen, A. E. Trefethen, S. C. Reddy, and T. A. Driscoll, "Hydrodynamic stability without eigenvalues", Science **261**, 578 (1993).

2. V. S. Mikhailenko, V. V. Mikhailenko, and K.N.Stepanov, Phys. Plasmas **18**, 062103 (2011).

3. V. V. Mikhailenko, V. S. Mikhailenko, Hae June Lee, and M.E. Koepke, Plasma Phys. Control. Fusion **55**, 085018 (2013).

4. V. V. Mikhailenko, V. S. Mikhailenko, Hae June Lee, M.E. Koepke, Phys. Plasmas **21**, 032118 (2014).

5. R. E. Waltz, G. D. Kerbel, J. Milovich, G. W. Hammett, Phys. Plasmas **2**, 2408 (1995).

6. G. M. Staebler, J. E. Kinsey, E. A. Belli, J. Candy, R. E. Waltz, C. M. Greenfield, L. L. Lao, S. P. Smith, B. A. Grierson, and C. Chrystal, Phys. Plasmas **21**, 055902 (2014)