Zonal flow relaxation in stellarators: theory and first experimental observation

J. A. Alonso[1], I. Calvo[1], E. Sánchez[1], J. L. Velasco[1], S. Perfilov[2], P. Monreal[1], F. I. Parra[3,4], and the TJ-II team

[1] *Laboratorio Nacional de Fusión, CIEMAT, 28040, Madrid, Spain*
[2] *National Research Center, Kurchatov Institute, 123182, Moscow, Russia*
[3] *Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford, OX1 3NP, UK*
[4] *Culham Centre for Fusion Energy, Abingdon, OX14 3DB, UK*

Turbulence simulations in both tokamaks and stellarators show that the formation of zonal flows (i.e. flows due to radially localised electrostatic potential perturbations that are constant on flux surfaces) is an ubiquitous non-linear saturation mechanism with favourable transport regulation effects [1]. These electrostatic potential structures are robustly generated by drift-wave turbulence, yet their saturated level and their effectiveness in regulating transport depends on the damping they undergo in the toroidal magnetic surfaces. The collisionless relaxation mechanisms, associated to neoclassical polarisation currents or the finite radial excursions of the particle orbits, were first studied in tokamaks by Rosenbluth and Hinton in [2]. Their results showed that zonal structures are not completely damped in axisymmetric systems and highlighted the importance of properly modelling, via kinetic theory, this damping in turbulence codes to obtain meaningful non-linear energy fluxes. The kinetic treatment of the problem of the collisionless, linear relaxation of an initial zonal electrostatic perturbation has become a standard test of gyrokinetic codes.

During the last decade, the Rosenbluth-Hinton analysis has been extended to general three-dimensional geometry [3,4,5,6]. First, it has been found that the collisionless relaxation of long-wavelength zonal perturbations has a stronger damping at infinite time (or lower residual level) compared to tokamaks. Second, the relaxation exhibits a low frequency oscillation as a specific feature of stellarator geometry. The characteristics of this oscillation, besides arguably more relevant for turbulence regulation, lend themselves to more straightforward experimental approaches. Recently, pellet injection experiments in the TJ-II stellarator have shown that the sudden perturbation of the distribution functions caused by the injection triggers a transient evolution of the zonal electrostatic potential with the oscillation predicted by kinetic theory [7]. This constitutes the first experimental observation of the basic zonal flow damping mechanisms.

In this talk we will review the basic theory of the collisionless relaxation of zonal electrostatic perturbations, as well as these pioneering experiments, and will discuss their implications and prospects for further research.

References

[1] Z. Lin, T. S. Hahm, W. W. Lee, et al., Science 18, 1835 (1998)
[2] M. N. Rosenbluth and F. L. Hinton, Phys. Rev. Lett. 80, 724 (1998)
[3] H. Sugama and T. H. Watanabe, Phys. Rev. Lett. 94, 115001 (2005)
[4] A. Mishchenko, P. Helander and A. Könies, Physics of Plasmas 15, 072309 (2008)
[5] P. Monreal, I. Calvo, E. Sánchez et al., Plasma Phys. Control. Fusion 58, 045018 (2016)
[6] P. Monreal, E. Sánchez, I. Calvo et al., arXiv:1701.02722
[7] J. A. Alonso, E. Sánchez, I. Calvo et al., Phys. Rev. Lett. (in press)