Simulation Study of Hysteresis in the Flux-Gradient Relation in Turbulent Transport

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Many experiments have revealed that a local and monotonous flux-gradient relation is insufficient to explain dynamics in toroidal plasmas, e.g. L/H transitions. To clarify the transport dynamics, response to active control with modulation is studied, and hysteresis in the flux-gradient relation is observed in experiments [1]. Here we investigated the plasma response by a global nonlinear turbulence simulation, using Turbulence Diagnostic Simulator (TDS) [2], and found hysteresis in the flux-gradient relation. The role of the finite radial width of fluctuations, which transmits the response to distant locations, are investigates.

In this study, drift-interchange modes in helical plasmas are analyzed using a reduced MHD model [2]. In the nonlinear saturated state, mode structures broadened in the radial direction (global mode), and localized near their rational surfaces (micro mode) are both excited. Response to heat source modulation, which is only applied near the plasma center and switched on and off periodically, is investigated. Characteristic response to the modulation is extracted by the conditional averaging over 100 periods of the modulation.

The modulation of the pressure propagates to the outer region with a speed of ten times faster than the diffusive response. This non-diffusive response is caused by the consecutive changes of the global mode structure at distant radii. When the heat source modulation is switched on, the heat flux (at the radius away from the source region) begins to increase as the local pressure gradient increases. When the modulation in nonlinear couplings reaches the radius of interest, enhancement of the mode amplitude and the heat flux takes place. The acceleration of the growth in the heat flux (without substantial change of the local pressure gradient) occurs with the delay time, which is of the order of the auto-correlation time of fluctuations. This response gives hysteresis in the counter-clockwise in the flux-gradient relation, which is different from the experimental observation in [1]. The essense in this nonlinear dynamics is that the radial profiles of the induced heat flux and of the nonlinear transfer to micro modes by the global mode are different. This difference determines the rotation direction in the hysteresis. This result implies the possibility that variety of hysteresis responses will be observed in fusion plasmas. There is experimental observation of global structures in torus plasmas [3], so the radial profiles of the field intensity and induced transport of the global mode should be investigated experimentally to clarify the mechanism in future.

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