§6. Evaluation of Spatial Variation of Nonlinear Energy Transfer by Use of Turbulence Diagnostic Simulator

Kasuya, N. (RIAM, Kyushu Univ.), Sugita, S. (IDEAS, Chubu Univ.), Sasaki, M. (RIAM, Kyushu Univ.), Inagaki, S. (RIAM, Kyushu Univ.), Yagi, M. (JAEA), Itoh, K., Itoh, S.-I. (RIAM, Kyushu Univ.)

Turbulence Diagnostic Simulator (TDS) [1)] is an assembly of simulation codes to clarify the formation mechanism of turbulent structures [2)] by numerical diagnostics in magnetically confined plasmas. Here, drift-interchange modes with a simplified helical plasma model are analyzed, using the TDS. Nonlinear energy transfer rate is evaluated to show multiple interactions of excited modes in the case with radially-spread modes [3)].

To provide turbulence data, a simulation code has been developed to calculate the drift-interchange turbulence in helical plasmas [3)]. The set of model equations consists of charge conservation, parallel component of induction equation and sum of pressure evolution equations. The ordering and averaging method with the stellarator expansion [4)] is applied to give the set of model equations. Global simulations are carried out using this reduced MHD model, and time series data of 3-D fluctuation fields are produced. A nonlinear simulation is performed, using the following parameters: magnetic field B_0 = 2.0 [T], density $n_0 = 1 \times 10^{19}$ [m^{-3}], beta ration β = 0.03, minor radius a = 0.6 [m], major radius R_0 = 3.75 [m] and specific heat ratio γ = 5/3. A fixed pressure source forms the profile peaked at r = 0 in the simulation.

In the nonlinear saturated state, mode structures of low m, n modes, such as (m, n) = (1, 1) and (2, 1), spread broadly in the radial direction, and those of medium m, n modes, such as (3, 2) and (5, 5), are localized near their rational surfaces, where m and n are the poloidal and toroidal mode number. With the existence of these localized modes, flattening of the mean profile occurs at the rational surfaces. There exist various sizes of vortexes in the poloidal cross-section, which rotate in the poloidal direction and are mixed with each other. There are low m modes spread in the radial direction, so mutual couplings with several modes are possible, due to their overlapping.

The contributions to energy evolutions from nonlinear couplings are evaluated in the saturated states to understand the spatial variation of the structural formation mechanism. As for the pressure fluctuations, the evolution equation of the internal energy includes the contributions from the linear term (LT, 1st term in the right hand side of the following equation) and nonlinear terms from the convective derivative (NT1, 2nd term):

$$\frac{\partial E_{Pmn}}{\partial t} = \frac{1}{2C}\int dr^3 P^* \times\left\{\left(\frac{\partial u_0}{\partial r}\frac{\partial P}{r\partial\theta} - \frac{\partial P_0}{\partial r}\frac{\partial u}{r\partial\theta} - \alpha C\frac{\partial \nabla_\perp^2 A}{\partial\zeta} + \alpha C\frac{\partial\Psi_0}{\partial r}\frac{\partial\nabla_\perp^2 A}{r\partial\theta}\right)_{mn} + [u,P]_{mn} + S_{mn}\right\} .$$

Figure 1 shows the radial profile of the nonlinear contribution to formation of the (m, n) = (0, 0) component of the pressure (P_{00}), where NT1 is decomposed into one with each poloidal mode number. In red regions, the P_{00} component gets the energy from modes with poloidal mode number m, and in blue regions, vice versa. The radial profile of NT1 indicates the characteristic regions; $r / a < 0.3$: strong mode excitation, 0.4 - 0.7: existence of various modes, > 0.8: existence of small number of dominant modes. The dominant mode to contribute to the P_{00} component changes according to the radial position, as indicated by the marks in the Fig. 1(a). There are low m modes ($1 \le m \le 3$) widely spreading in the radial direction (Fig. 1 (b) 1)), which contributes to the nonlinear structural formation, especially in $r / a < 0.3$. In addition, there is a radial region where nonlinear couplings with higher m modes contribute to the pressure profile modification in r / a = 0.5 - 0.7 (Fig. 1 (b) 2)). The profile modification arises in this region, and propagates to the other regions. As for the flow generation, the main cause of the ϕ_{00} oscillation is the coupling between ϕ_{00} and $P_{\pm 10}$.

The phenomena described in this simulation is the case with dynamical coupling of modes excited at each rational surface, and widely spread in the radial direction, which gives large correlation between separated radial positions. The radial profiles of nonlinear contribution, as shown in Fig. 1, are instructive for the experimental detection of this kind of phenomena. For the detection of the different features, combination of several diagnostics is necessary. In this way, turbulence analysis using simulation data can give the insight for the physical mechanisms in plasmas. Common methods can be applied to various simulation data for the cross-validation using the TDS.

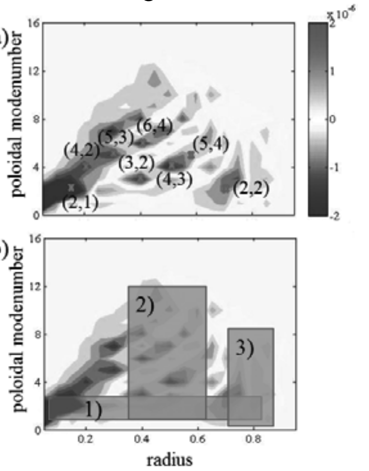

Fig.1: Radial profile of the nonlinear contribution to the P_{00} evolution, which is decomposed into each poloidal mode number component. (a) Mode numbers of the main contributors on each peak and (b) characteristic regions of the nonlinear couplings are also shown.

1) Kasuya, N. et al.: Plasma Sci. Technol. **13** (2011) 326.
2) Diamond, P. H. et al.: Plasma Phys. Control. Fusion **47** (2005) R35.
3) Kasuya, N. et al.: Plasma Fusion Res. **8** (2013) 2403070.
4) Wakatani, M.: *Stellarator and Heliotron Devices* (Oxford University Press, Oxford 1998).