§8. Spatiotemporal Dynamics and Transport Reduction in Helical Magnetic Configuration

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Zonal flows, sheared $E\times B$ plasma flows possessing toroidal and poloidal symmetries, have been investigated in numerous theoretical, numerical and experimental studies as one of the main mechanisms regulating turbulent transport in magnetic confinement fusion. The analysis presented here of the nonlinear gyrokinetic Vlasov simulation (GKV) results, performed from the aspect of nonlinear dynamic systems theory, shows that the reduction of transport in the inward shifted configuration may also be a direct consequence of spatiotemporal chaos suppression. Hence, inward shifted helical configuration may represent means for control of spatiotemporal chaos. The basic formulae for describing the drift wave turbulence in magnetically-confined plasmas are given by the gyrokinetic equations, where time-evolution of the one-body distribution function is described as a nonlinear partial differential equation defined on the five-dimensional phase space. A detailed account of the GKV simulation model may be found in Ref. 1. Magnetic configuration models relevant to the LHD experiments with the inward-shifted and standard plasma positions are employed in the GKV code[2]. In Figs 1 and 2 the spatiotemporal (ST) profiles of the electrostatic potential of the zonal flow for the standard (SC) and the inward shifted (ISC) configurations are presented. We extract the Lyapunov spectrum of exponents (LS) $\{\lambda_i, i=1,N\}$ for $\phi(x,t)$. The spectrum is then used to obtain the dimension of the chaotic attractor (the number of effective degrees of freedom) which is given by the so called Lyapunov dimension (D_L). In Fig. 3 the sum of Lyapunov exponents is presented as a function of i for various sizes of the system. From this representation D_L may be readily obtained from the intersection with the horizontal axis and the Kolmogorov-Sinai entropy h is determined from the maximum of the curve.

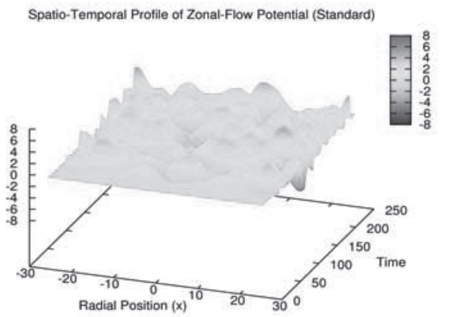

Fig. 1 ST profile of ϕ for the SC of the (LHD)

It may be easily noticed that both D_L and the h of the standard shifted configuration (black curves) are always greater than D_L and h of the inward shifted one (gray lines).

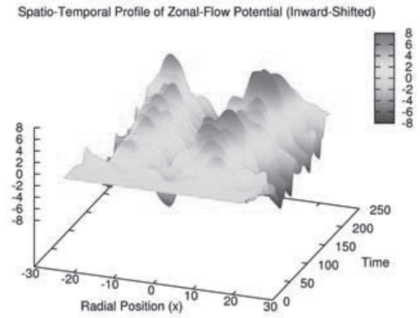

Fig. 2 ST profile of ϕ for the IS configuration of the LHD.

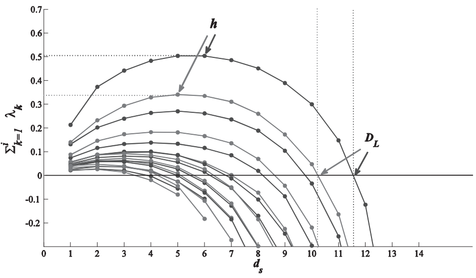

Fig. 3 The sum of Lyapunov exponents for SC and ISC

It is clear that both D_L and h are extensive quantities. Hence, the standard configuration is more chaotic with the greater number of effective degrees of freedom and the mean rate of information production is higher in the standard. Further comparison between the dynamics in two configurations may be obtained by using the recurrence plot (RP) analysis of time series[3] which offers remarkable visual difference between the dynamics in two configurations. For this purpose we use temporal variations of electrostatic potential at the central spatial (radial) position i.e. $\phi(x=0)$. Using standard methods to embed the time series we obtain the recurrence plots shown in Fig. 4 for the SC (left) and for the ISC (right). SC plot reveals irregular diagonal areas with sparsely distributed horizontal and vertical areas (lines) indicative of deterministic chaos[3]

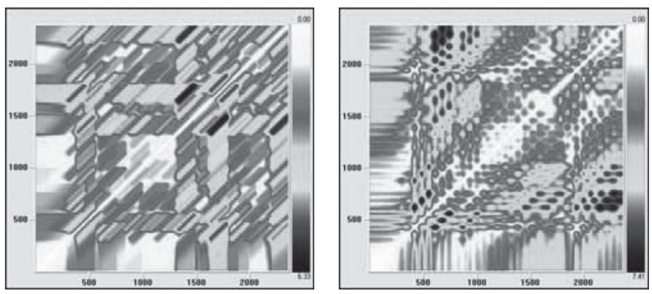

Fig. 4 Recurrence plots of time series $\phi(t,x=0)$; SC is on the left and ISC on the right.

1) S. Ferrando-Margalet et al, Phy. Pl., 14, 122505 (2007).
2) T.-H.Watanabe et al., PRL 100, 195002 (2008).
3) J.-P.Eckmann et al., Rev. Modern Phys., 57, 617 (1985).