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Study of nonlinear internal and kinetic energy exchange between turbulence and shear flows via cross-bispectrum analysis on HL-2A tokamak

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It is proved that poloidal shear flow is the key to the suppression of turbulent transport and confinement improvement on tokamak plasma [1-3]. Mean shear flows (MSF) induced by radial press gradient can be enhanced by the nonlinear interaction between turbulence and MSF [4]. Meanwhile, zonal flows, including low-frequency zonal flows (LFZF) and geodesic acoustic modes (GAMs) can only be generated by nonlinear energy transfer from drift wave turbulence to ZF [1]. Thus, the study of this nonlinear energy transfer process will directly address the underlying physical mechanism of zonal flow generation and MSF enhancement.

Earlier studies have shown the nonlinear interaction between poloidal shear flows and turbulence is predominated by three-wave coupling process. Bispectrum analysis method was introduced to study plasma turbulence study by Kim and Powers [5], and then developed to investigate turbulence linear growth rate, dispersion relation and wave-wave coupling coefficient, quantitatively [6], basing on substantial high spatial and temporal experimental data measured by Langmuir probes, beam emission spectroscopy, etc. A newly developed method took advantage of cross-bispectrum analysis in frequency domain [7], and was applied on the nonlinear internal and kinetic energy transfer on CSDX [8] and HL-2A tokamak [9]. Based on electron continuity equation and ion momentum equation, the frequency-resolved internal and kinetic energy gain were achieved respectively. The spectral analysis gives more details about the energy exchange process, including distinguish GAM, zonal flows and turbulent flows in frequency domain.

This nonlinear energy exchange process has been investigated in the framework of *K*-ε model on CSDX, a magnetized cylinder device, as well [11]. It is clear that the convective term in the ion momentum equation arises the three-wave coupling process and cause kinetic energy exchange between different fluctuation scales and spatial transport. The cross-bispectrum analysis applied in the reference [9] presents the total energy gain of each frequency on local position, without distinguishing the contribution of the energy exchange and the spatial transport.

In this work, we will apply cross-bispectrum method on the kinetic energy exchange study during wave-wave coupling process on HL-2A Ohmic and L-mode plasmas in frequency domain. Earlier work has shown total energy gain for each frequency band and it will be divided to two part, the spatial transport and spectral exchange, and investigated separately. The results show that spatial transport and spectral exchange are quantity-comparable. The shearing of zonal flows will transfer turbulence energy to shear flows while GAMs will also modulate turbulence, causing inverse energy cascade in turbulence frequency band.

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