Experimental Evidence of Nonlinear Avalanche Dynamics of Energetic Particle Modes

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The nonlinear interactions between energetic particle (EP) and Alfvén waves are very important for astrophysics and high temperature plasma physics, especially for magnetically confined fusion plasma, because they will affect the redistribution and transport of EPs significantly. Some early nonlinear theories [1-3] have addressed the role of the EPs radial displacements on the time evolution of a strongly driven mode such as the EPM [4-7]. The expected self-consistent nonlinear evolution of the EPM and the EPs have not been unambiguously observed in experiments up to now. New experimental evidence of EPM avalanche is found in the HL-2A tokamak [8].

In the strong EPM burst, the poloidal mode number changes rapidly from m=2 to 3, and then becomes 4 step by step. The change of m can be completed within Δt=0.06 ms. The ratio of typical growth time of EPM to Alfvén time is τ/τ_A~200, which is in the expected range where convective EP redistributions can take place [8-10]. The toroidal mode number is confirmed always as n=1 during the whole chirping down process. It is indication that the EPMs move from the plasma core ($q=m/n$=2, where q is the safety factor) to the plasma edge (q=3 and 4). The EPM mode structure and their evolution in poloidal cross section are obtained by tomography of SXR arrays. The m/n=2/1 mode mainly locates in the plasma core at first. Then, the modes propagate to the edge gradually. At last, the edge (m=3 and 4) elements become dominant.

According to the relay runner model (RRM) [2], for dominant circulating particles driven EPM at transit resonance, as in the HL-2A experiments, the relationship between the EMP chirping rate ($\dot{\omega}$) and A in experiment satisfies the scaling $A \propto q\dot{\omega}$, as shown in Figure.1. The average radial velocity of the waves (V_p) estimated by the ratio of the distance from q=2 to 4 rational surfaces (Δr) to the time interval (Δt) is close to the radial velocity of EP ($\dot{r}$) predicted by the RRM model. Compared with results from theory and experiment, we obtained $|\dot{r}/V_p| \approx O(1)$, i.e., the observed mode radial propagation velocity is comparable to that of EPs, as predicted by RRM model.

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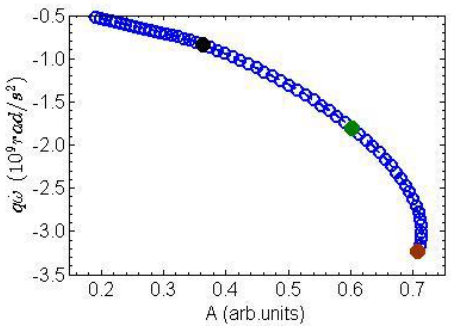

Figure.1 Relationship between A and $q\dot{\omega}$ in experiment during t=618.62-618.68 ms. The black, green and brown circles present the relationship in q=2, 2.5 and 3 conditions.