§21. Study on Dynamo Turbulence Fluctuation on the Helicity Injected Spherical Torus (HIST) Device

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The magnetically confined high-beta plasmas such as spheromak, RFP and spherical torus have the self-organizing features represented by magnetic reconnection, kink instabilities, wave excitation and ion heating whose phenomena are observed in space as well. Dynamical process of explosive plasmoid ejection and magnetic field's twisting and reconnection could account for the various phenomena called astrophysical jets, solar coronal loops and Jupiter's zonal flow driven by thermal convection. For fusion plasmas, to control externally plasma flow or rotation plays an important role on maintaining high-beta confinements with an optimized pressure gradient. It is well known that for example, the H-mode transition in tokamak plasmas is created by inward radial electric field and poloidal shear flow. Suppression of turbulent transport by zonal flow also was observed so far. Dynamo fluctuations generated by helicity injection can be understood as non-inductive current drive mechanism in fusion plasmas. We observe a large fluctuation-induced electromotive force during helicity injection which is capable of generating plasma current in the closed flux region. Detailed measurements of the spatial and temporal dynamics of dynamo electric field and density fluctuations will provide us further understandings of dynamo mechanism leading to control of turbulent transport in fusion confinements.

We have investigated dynamo current drive in the HIST device. Coaxial Helicity Injection (CHI) on HIST has generated toroidal plasma currents up to 100 kA. The CHI operation has sustained the toroidal current for a long time against resistive decay. The internal magnetic field measurements have verified the flux amplification and the closed flux surfaces created due to dynamo actions. We have studied characteristics of the plasma flow and the magnetic field structures during the sustainment. The observed poloidal shear flow can be explained in terms of the ion diamagnetic drift that is responsible for the steep density gradient between the central open flux column and the closed flux region. These results are confirmed with help of 3D-MHD computational simulation.

The frequency of the magnetic field and flow velocity fluctuations peaks around 80-100 kHz during the CHI. The coupling of these fluctuations generates dynamo electric fields. Equation (1) is the parallel mean-field Ohm's law which is in the two-fluid description.

$$\eta \boldsymbol{j}_{\parallel 0} - \boldsymbol{E}_{\parallel 0} = <\delta v \times \delta \boldsymbol{B}>_{\parallel} - <\delta \boldsymbol{j} \times \delta \boldsymbol{B}>_{\parallel} / \mathrm{en} \approx -<\delta \boldsymbol{v}_{\mathrm{e}} \times \delta \boldsymbol{B}>_{\parallel} \quad (1),$$

where < > denotes a mean or ensemble-averaged quantity. The MHD dynamo (first term on the right-hand side) arises from the correlation of magnetic and flow velocity fluctuations and the Hall dynamo (second term on the right-hand side) arises from the coherent interaction of magnetic and current density fluctuations.

Figure 1 shows the radial profile of the Hall and MHD dynamo electric fields that have been measured for the first time. Sign of the total dynamo reverses at the separatrix layer. Note that there is anti-dynamo in the open flux column region where is a helicity source, and dynamo in the closed flux region which drives the toroidal current in core. We can identify the inward helicity flow. In the lower density operation regime, the Hall effect becomes more significant. The relative contributions of the different dynamo electric field on the driven current make the mean Ohm's law balance. It is found by these measurements that two-fluid Hall dynamo is essential to the CHI current drive mechanisms.

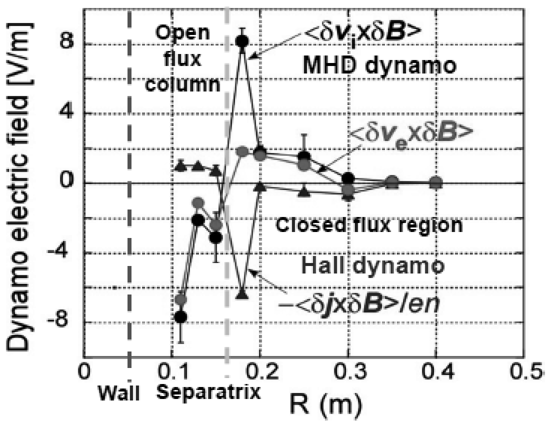

Fig. 1. Radial profiles of dynamo electric fields.

We are starting to construct a Microwave Interferometer Imaging (MIR) diagnostics system to measure density fluctuations during the CHI. The MIR system on HIST is designed, shown as Fig. 2, and preliminary experiment has been performed. The U band frequency (40-60 GHz) is suitable for the measurement of the edge density fluctuation on HIST ($n_{e,edge}$~3×10^{19} m^{-3}). The imaging 2D array antenna, which has been developed for LHD, can be used on HIST. In initial design, a horn antenna is applied for the check of stray light.

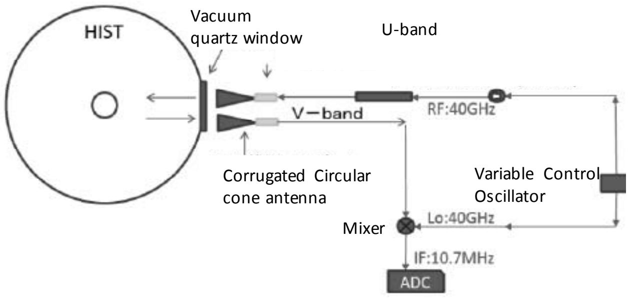

Fig. 2. Design of Microwave Interferometer Imaging on HIST deice.