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Measurement of Hall dynamo during CHI current driven phase on HIST

HISTプラズマのCHI電流駆動過程におけるホールダイナモ計測

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We have measured the dynamo electric fields necessary to balance the mean field Ohm's law in the helicity-driven ST plasmas in double pulsing Coaxial Helicity Injection (CHI) discharges on HIST. The dynamo measurement indicates that the Hall and MHD dynamo induced electric fields are large enough to sustain the mean toroidal current against resistive decay in the core region. Two-fluid Hall dynamo is found to be essential to the CHI current drive mechanisms.

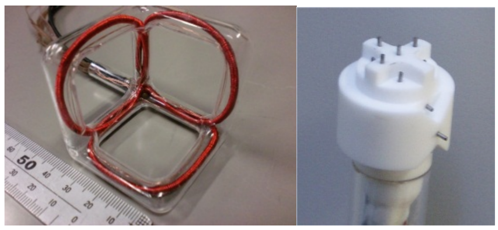
1. Introduction

Coaxial Helicity injection (CHI) is an efficient current-drive method used in spheromak and spherical torus (ST) experiments. An anticipated issue for CHI is achieving good energy confinement, since it relies on the magnetic relaxation and dynamo. This is essentially because CHI cannot drive a dynamo directly inside a closed magnetic flux surface. Thus, it is an important issue to investigate dynamo effect to explore CHI current drive mechanisms in a new approach such as Multi-pulsing CHI method. To study the dynamo model with two-fluid Hall effects, we have started from the generalized Ohm law.

To study the dynamo model with two-fluid effects, we start from the generalized Ohm law, $\eta\boldsymbol{j}=\boldsymbol{E}+\boldsymbol{v}\times\boldsymbol{B}-\boldsymbol{j}\times\boldsymbol{B}/en+\nabla p_e/en$, where η is the plasma resistivity, n the electron density and p_e the electron pressure. We decompose each quantity into mean and fluctuating part, and take the ensemble average of the parallel component of it for turbulent equilibrium plasmas to yield the parallel mean-field Ohm's law $\eta\boldsymbol{j}_\parallel - \boldsymbol{E}_\parallel = \langle\delta\boldsymbol{v}\times\delta\boldsymbol{B}\rangle_\parallel - \langle\delta\boldsymbol{j}\times\delta\boldsymbol{B}\rangle_\parallel/en \approx \langle\delta\boldsymbol{v}_e\times\delta\boldsymbol{B}\rangle_\parallel$, where $\boldsymbol{v}_e$ is electron velocity, δ denotes a fluctuating quantity, $\langle\ \rangle$ denotes a mean quantity [1]. The first of these terms in the right-hand side (RHS) represents the MHD dynamo $\langle\delta\boldsymbol{v}\times\delta\boldsymbol{B}\rangle_\parallel$, while the second is the Hall-dynamo $\langle\delta\boldsymbol{j}\times\delta\boldsymbol{B}\rangle_\parallel/en$. In this experiment, we have studied each dynamo term at the same time.

2. Diagnostics

We have measured each MHD dynamo term and Hall dynamo term separately by using Mach probe and Hall probe involving 3-axis magnetic pick-up coils as shown by Fig.1. The Mach probe incorporates three-axis magnetic pick-up coils to measure MHD dynamo induced electric field. A pair of two tip electrodes on the Mach probe is used as a double probe to measure local electron density. Hall dynamo probe is covered by a glass tube with a square of 30mm × 30mm in the three directions, and contains a Rogowski coil and 3 turns loop coil in it. Thereby, we can obtain the local data of the current density and the magnetic field. The Hall probe and Mach probe are inserted at the same position in the flux conserver (FC) as shown by Fig.2.



(a) (b)

Fig.1. Hall probe (a) and Mach probe (b)

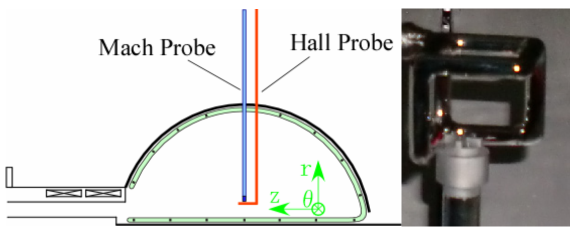


Fig.2. Mach and Hall probes inserted in the FC

3. Experimental results

Figure 3 shows the time evolution of MHD dynamo, Hall dynamo and toroidal current density in the central open flux column (OFC) and the core regions. The direction and amplitude of each dynamo are determined by the phase difference between the fluctuating velocity or current density and the fluctuating magnetic field. After injecting 1st gun pulse, the toroidal current has increased and the response times of the MHD and Hall dynamo induced field shows a good correlation with the pulse-like current generation. After then, the 2nd gun-pulse seems to keep driving the current not only in the open flux column region but also in the core region. We have checked the Ohm's law balance in the both regions. The estimation result indicates that the both fluctuation-induced electromotive forces are large enough to sustain the mean toroidal current. The parallel mean-field Ohm's law balance is roughly satisfied both in the OFC driven-region and the core region.

Figure 4 shows the MHD and Hall dynamo induced electric fields measured at each radial position. The induced field due to MHD dynamo is found to be sufficent to sustain the mean toroidal current against resistive decay in the core region. In the other hand, the anti-dynamo effect in the MHD dynamo term is observed in the OFC region. From the viewpoint of two-fluid theory, ion diamagnetic drift is opposite to the electron diamagnetic drift, maybe resulting in the anti-dynamo effect. Hall dynamo may arise from the fluctuating electron diamagnetic current due to high electron density gradient which is large in the OFC region.

Note that the direction of the ion flow observed in the OFC is opposite to that of the electron. The ion is accelerated due to the Hall dynamo electric field and the electron becomes slow down due to the anti-MHD dynamo. In the core region, collisional drag of electrons accelerates the ions and so the ion and electron flows have the same direction. The dynamics of the ion and electron flows may be consistent with the electron locking model [2].

4. Summary

We have measured directly and simultaneously the Hall and MHD dynamo spatial profile. The relative contributions of the different dynamo electric field on the driven current have been examined to verify mean Ohm's law balance. The Hall dynamo acts to generate the mean current density in the both regions, although anti-MHD dynamo is effective in the OFC region. Both dynamos play an important role in the helicity injection current drive.

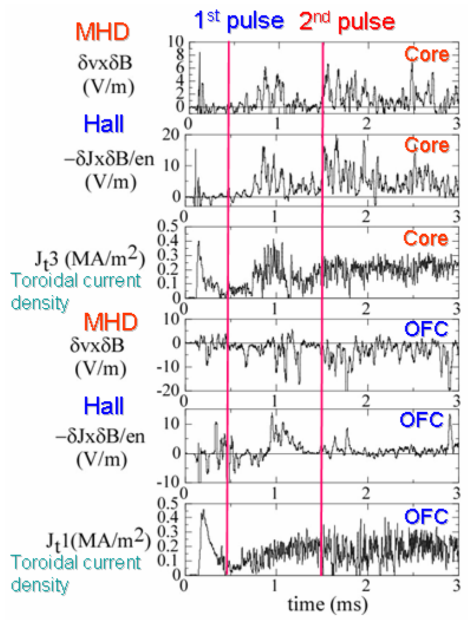


Fig.3. Time evolution of the Hall and MHD dynamo induced electric field and the toroidal current density in both the open flux column and the core region.

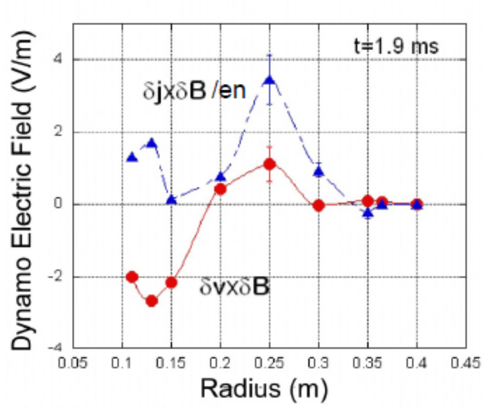


Fig.4. Radial profiles of the MHD dynamo (red) and Hall dynamo (blue) induced electric field in the driven phase.

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References

[1] H. Ji, et al., Phys. Plasmas **3**, 1935 (1996).
[2] T.R. Jarboe et al., Nucl. Fusion **51,** 063029 (2011).