21PA-008

Alfven wave and dynamo current drive on HIST
HIST球状トーラス装置におけるアルヴェン波とダイナモ電流駆動

M. Nagata, T. Hyobu, H. Hirono, T. Hanao, N. Oki, Y. Kikuchi, N. Fukumoto
永田正義、兵部貴弘、廣納秀年、花尾隆史、沖伸晴、菊池祐介、福本直之

Graduate School of Engineering, University of Hyogo
2781 Shosha, Himeji, Hyogo 671-2280, Japan
兵庫県立大学・大学院工学研究科 〒671-2280 兵庫県姫路市書写2167

The dynamo current drive with two-fluid effects has been investigated in the helicity-driven spherical torus (ST) plasmas on HIST. 2D internal magnetic field measurements of the ST configuration has verified the flux amplification and the generation of the closed flux during the coaxial helicity injection (CHI). We have found that not only MHD $<\delta\boldsymbol{v}\times\delta\boldsymbol{B}>_{\parallel}$ dynamo but also Hall $<\delta\boldsymbol{j}\times\delta\boldsymbol{B}>_{\parallel}/en$ dynamo plays an important role in the helicity transport for the current sustainment. Hall-MHD induced-electric fields satisfy the parallel mean-field Ohm's law balance. We have also observed transverse propagation and damping of a low-frequency Alfven wave. The measured resonance and cut-off points agree with those calculated from the dispersion relation of Alfven wave based on the warm model. The increase in perpendicular wave number and the phase velocity has been verified during radial propagation of the Alfven. This is possibly mode conversion to kinetic Alfven wave (KAW), which results in the heating of ions. The dynamo activities for the current drive are related to the propagation of the Alfven waves.

1. Introduction

The steady-state current drive by the coaxial helicity injection (CHI) had been demonstrated for spheromaks (SSPX) and ST plasmas (HIST, HIT-II). Recently, the new approach of CHI so called the multi-pulsing CHI (M-CHI) operation [2] has been proposed for the purpose of achieving a quasi-steady-state high-β ST plasma. As an application of M-CHI for the ST configurations, we have started double-pulsing CHI experiments in the HIST device (R = 0.30 m, a = 0.24 m, A = 1.25) as shown in Fig.1. It is one of main objectives in this experiment to understand the underlying dynamo current drive mechanism during the helicity transfer from the coaxial plasma gun to the closed flux region. Flux amplification and current drive by dynamo effect is one of the most interesting physical phenomena in astrophysical and laboratory plasmas. The CHI pulse produces effectively fluctuating flows and magnetic fields which are considered to be dynamo activities needed for driving a current in the closed flux regions. The CHI current drive exhibits the significance of two-fluid effects. This paper will present an experimental study of flow generations and dynamo current drive with Hall-MHD based models.

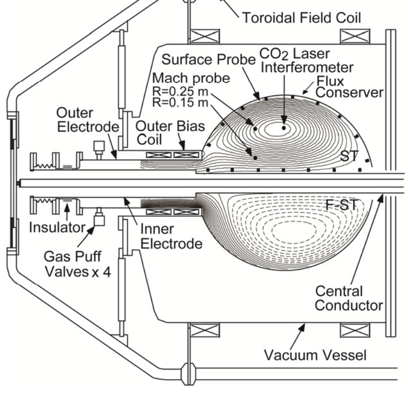

Fig. 1 HIST device

2. Two-fluid dynamo

Flux amplification and current drive are attributed to dynamo action induced by the helicity injection. Two-fluid effect has been measured to be large between the open flux column (OFC) region and the last closed flux surface, i.e., at the separatrix due to the steep pressure gradient. 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 $\eta\boldsymbol{j}_{\parallel} - \boldsymbol{E}_{\parallel} = <\delta\boldsymbol{v}\times\delta\boldsymbol{B}>_{\parallel} - <\delta\boldsymbol{j}\times\delta\boldsymbol{B}>_{\parallel}/en \approx <\delta\boldsymbol{v}_e\times\delta\boldsymbol{B}>_{\parallel}$, where $\boldsymbol{v}_e$ is electron velocity, δ denotes a fluctuating quantity, < > denotes a mean quantity. The first of these terms in the right-hand side (RHS) represents the MHD dynamo $<\delta\boldsymbol{v}\times\delta\boldsymbol{B}>_{\parallel}$, while the second is the Hall-dynamo $<\delta\boldsymbol{j}\times\delta\boldsymbol{B}>_{\parallel}/en$. In this experiment, we have measured separately each dynamo term at the same time.

Figure 2 shows the MHD and Hall dynamo induced-electric fields measured at each radial position. 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. It is noted that the MHD dynamo has the opposite direction to the Hall dynamo. The both fluctuation-induced electromotive forces are large enough to sustain the mean toroidal current against resistive decay in the core region. The parallel mean-field Ohm's law balance is roughly satisfied both in the OFC driven-region and the core region during the current sustainment.

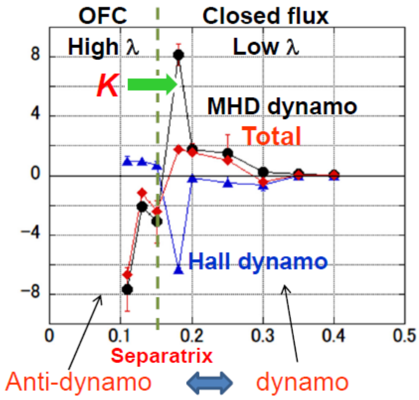

Fig.2 Radial profile of MHD dynamo and Hall dynamo in the driven phase.

3. Alfven wave and dynamo

We have investigated propagations of magnetic fluctuations in the poloidal cross section of the plasma. The magnetic fluctuation originates from the muzzle of the magnetized coaxial plasma gun (MCPG) like an antenna. Figure 3 shows the time evolution of the radial profile of the magnetic fluctuations. The frequency of the observed oscillation is ~80 kHz for I_{tf}=100 kA. The parallel phase velocity $v_{//}$ is 324 km/s that is estimated by the axial propagation velocity ~70 km/s along the OFC, and then the parallel wave number $k_{//}$ ~ 0.25 m^{-1} can be obtained. The parallel phase velocity agrees well to the Alfven velocity v_A. The radial propagation of the Alfven wave can be calculated by a theory based on a cold plasma approximation with the Hall term. The theoretical calculation using the measured $k_{//}$, the measured density profile and the magnetic field profile indicates that the Alfven wave has a cut off (R=0.27 m) and two resonances (R=0.2, 0.36 m) at a radial position. The shear Alfven wave propagates inwardly towards the magnetic axis beyond the first resonance from the OFC region edge (R=0.15 m). The wave decays rapidly after encountering the cut-off position. In the warm plasma model, the shear Alfven wave does not have a sharp resonance, and continuously converts to high perpendicular k mode called "kinetic Alfven wave". The experimental result indicates that the phase velocity decreases and the perpendicular k increases to the value close to that of the kinetic Alfven wave predicted from the warm plasma theory. This mode conversion leads to the heating of ion due to resistive damping. As shown in Fig. 3, the wave has propagated in the perpendicular (to the vacuum toroidal field) direction in the core region across the separatrix. The observed strong attenuation in the area (R>0.28 m) indicates that the resistive damping enables possibly the heating of ions which has been observed by Doppler ion temperature measurement.

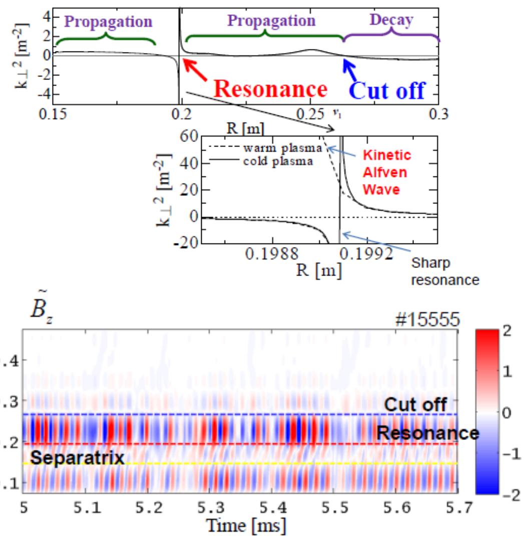

Fig. 3 Radial propagation of Alfven wave

4. Summary

We have measured the spatial profiles of the MHD/Hall dynamo electric fields being associated to the flux amplification by the successful double CHI pulses. The relative contributions of the different dynamo during the current drive have been investigated to verify the parallel mean-field Ohm's law balance. Contribution of the MHD dynamo in the core region with a higher density becomes more dominant compared to the Hall dynamo. In a low density plasma, however, the Hall dynamo becomes more significant as two-fluid effects. We have identified that the low-frequency Alfven wave with the peak frequency of 80 kHz for I_{tf}=100 kA propagates to the closed flux region. Moreover, we have observed that the ion Doppler temperature increases after the second CHI pulse.