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# Plasma Flow in a Linear Magnetized Plasma

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## Introduction

In order to study the nonlinear interactions between the instability, turbulence, and meso-scale as well as large-scale structures, we have been investigating the drift wave turbulence in a linear magnetized plasma. In the previous numerical investigation [1], it was shown that the growth rate of the drift waves turbulence is strongly depends on the ion-neutral collisions. This suggests a necessity to control the neutral density to realize the drift waves turbulent. Furthermore, a Monte-Carlo simulation on neutral particles in the plasma has suggested that the ion flow velocity is one of the key parameters which control the neutral density.

In this paper, we present a study of control methods of the neutral density for realizing a condition where the drift wave becomes unstable by the extended MHD simulation, Monte-Carlo simulation, and laboratory experiment. By the extended MHD simulation, a threshold of ion-neutral collision frequency for drift wave excitation is estimated. Effects of the Mach number (the plasma flow velocity normalized by the ion acoustic velocity), the electron temperature, and the baffle plate on the neutral density profile are also investigated by the Monte-Carlo simulation. Furthermore, the Mach number and the ion and neutral temperature are measured by the Mach probe and spectrometer in the linear magnetized plasma to obtain basic data for establishing a control method of the neutral density, leading to excite the drift wave turbulence. The laboratory experiment is performed using the Large Mirror Device (LMD) of the Kyushu University [2]. Note that parameters used in the simulations are close to those in the LMD.

## Extended MHD Simulation

The linear eigenmode analysis was performed to examine a necessary condition for drift wave excitation. A three-dimensional numerical simulation code called “Numerical Linear Device” has been developed [1]. The three-field (density, potential, and parallel velocity of electrons) reduced MHD model is extended to describe the

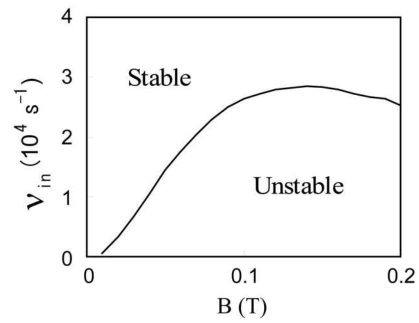


Fig. 1: Stability threshold of the ($m$, $n$) = (1, 1) mode on the $B$–$\nu_{in}$ phase space.

resistive drift wave turbulence in cylindrical magnetized plasmas. An upper bound of ion-neutral collision frequency $\nu_{in}$ was obtained, below which the turbulence can be excited. Figure 1 shows the threshold on the $B$–$\nu_{in}$ phase space ($B$: magnetic field, the electron temperature $T_e$ = 4 eV, the plasma radius $a$ = 7 cm, the device length $\lambda$ = 170 cm, and Gaussian radial density profile). The threshold value of $\nu_{in}$ is 2.5 $10^4$ $s^{-1}$ when $B$ = 900 G. It is necessary for exciting the turbulent resistive drift wave to make $\nu_{in}$ smaller by reducing the neutral density, $n_n$, and/or by increasing the ionization ratio.

## Monte-Carlo Simulation

The distribution of $n_n$ in the device was numerically evaluated by means of the Monte-Carlo method [3]. In the present calculation, the neutral self-elastic- collision is important because of a relatively high neutral pressure. The neutral particles are supplied both by a gas injection and by a recombination of ions at boundaries. For simplicity, the recombination in the plasma is regarded to take place at the lateral surface of the plasma column.

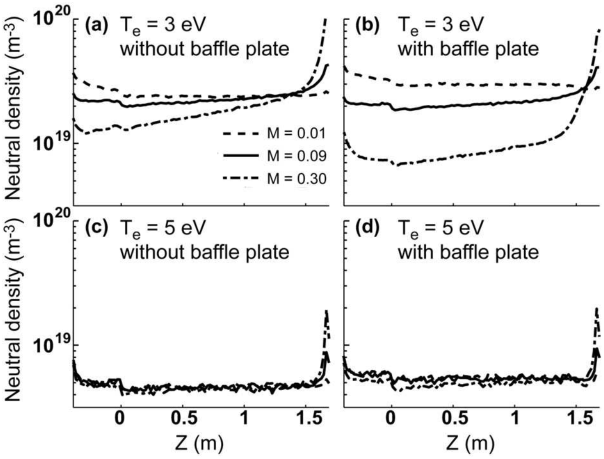


Fig. 2: Effect of Mach number, $M$, on the axial profile of neutral density at $r$ = 2.5 cm; $T_e$ = 3 eV (a, b) and 5 eV (c, d) without the baffle plate (a, c) and with the plate (b, d).

In the simulation, $a$ is 5 cm and the radial electron density profile is taken to have a parabolic form with the maximum value of $10^{13}$ $cm^{-3}$. Here, a pump with a pumping speed of 400 $l$/s is located at $z$ = 165 cm, and typical values of $T_e$, 3 and 5 eV, are used with the fixed ion temperature of 0.5 eV. The flux of the neutral gas at the production tube area ($z < 0$) is adjusted to coincide with the gas pressure of 1 mTorr.

When the electron temperature is low, $T_e$ = 3 eV, $n_n$ at $r$ = 2.5 cm strongly depends on the Mach number $M$ of the axial plasma flow, as shown in Figs 2 (a) and (b). In the case of $M$ = 0.01, the axial $n_n$-profile is mainly determined by the recombined neutral particles coming out of the lateral plasma. The presence of the baffle plate, located at $z$ = 150 cm, increases $n_n$ in the main region. In contrast, the larger $M$ enhances the recombination at the end-plate ($z$ = 170 cm), and $n_n$ in the main plasma is reduced by using the baffle plate. There is a critical Mach number, $M_c \approx 0.08 - 0.09$, above which the baffle plate does not affect the $n_n$-profile.

If the electron temperature is high, $T_e$ = 5 eV, $n_n$ at $r$ = 2.5 cm is small comparing to the averaged neutral density in the radial direction, as shown in Figs. 2 (c) and (d). This means that the ionization rate in the plasma is high. Here, $n_n$-profile is almost determined by the particles recombined at the plasma surface, and the contribution of the recombination at the end-plate is weak. Therefore, $n_n$ does not strongly depend on $M$. The averaged axial $n_n$-profile is almost flat, since the recombination takes place everywhere at the plasma boundary.

## Laboratory Experiment

In developing the drift wave turbulence, the importance of the plasma flow speed and $n_n$ was clarified in the preceding sections. To establish a way to control $n_n$ for turbulent experiments in the near future, the Mach probe and spectroscopic measurements have been executed on the LMD. An axial length of the device, with a magnetic field (up to 1.2 kG), was 170 cm and an inner chamber diameter 44.5 cm. High-density plasma was produced by a double-loop antenna equipped at one end of the device with an injecting rf-power of 2 kW. A baffle plate of 20 cm in diameter was placed at $z$ = 120 cm. Two conventional Mach probes were inserted, whose electrodes were 4 mm in length and 0.8 mm in diameter. One probe was movable along the radial direction at $z$ = 158 cm; the other scanned the plasma fan-wise so as to move in the $z$-axis ($125 < z \leq 165$ cm).

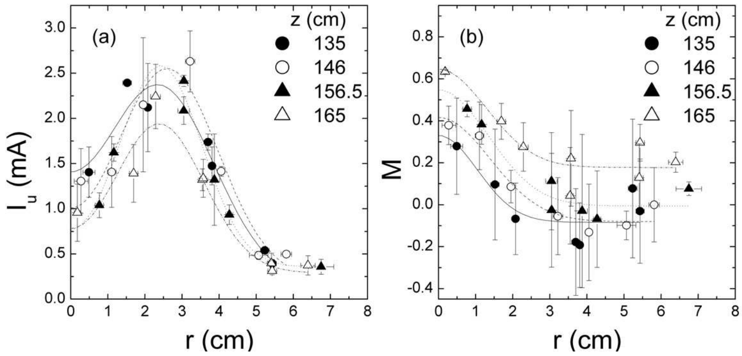

Fig. 3: Radial distributions of the ion saturation current detected by the upstream electrode of the Mach probe (a) and the Mach number (b) at several $z$'s.

Argon gas was fed at a pressure of 1 mTorr. In the present experiment, the magnetic field was uniform and its strength was 900 G. The electron temperature was estimated to be around 4 eV and the plasma density was up to $10^{13}$ cm$^{-3}$. From the Mach probe measurement, the radial profile of the ion saturation current ($\propto$ the electron density as long as $T_e$ is constant) was hollow as shown in Fig. 3 (a). There was a tendency that the $z$-profile of this current decreased slightly with increasing $z$. Figure 3 (b) shows the radial profiles of $M$ for various axial positions. In the central region of the plasma, $M = \ln (I_u/I_d) / \kappa \approx 0.3$ at $z$ = 135 cm in case of the unmagnetized-kinetic model ($\kappa$ = 1.26) [4], where $I_u$ and $I_d$ were the ion saturation currents of the Mach probe facing the upper and the lower streams of the plasma flow, respectively. In determining $M$, there was an ambiguity by a factor of ~ 2, depending on physical models. Approaching the end-plate, there was a tendency that $M$ increased gradually.

The ion and neutral temperatures were measured by a spectrometer with a focal length of 1.5 m, and the observation points were at $z$ = 108 and 151 cm. The observed lines were visible of 420.068 nm (ArI), 434.845 nm (ArII), and 487.986 (ArII). The ion and neutral temperatures in the central plasma region were $T_i \approx 0.6$ eV and $T_n \leq 0.2$ eV, respectively.

**Summary**

We have been investigating the drift wave turbulence in the linear magnetized plasma. To realize the fully developed drift wave turbulence in the device, the ion-neutral collision frequency has to be less than the threshold value by reducing the neutral density and/or by increasing the ionization ratio from the MHD simulation.

The Monte Carlo simulation has shown that the Mach number, $M$, and the electron temperature, $T_e$, affect the neutral density profile. When $T_e$ is low, the neutral density, $n_n$, depends on $M$. The baffle plate increases (decreases) the neutral density if $M$ is below (above) the critical value. When $T_e$ is high, the ionization rate rises and the neutral density does not strongly depend on $M$.

The electron density has a hollow profile under the present experimental condition. Based on the unmagnetized kinetic model, $M$ was 0.3 (up stream) ~ 0.6 (near end-plate). This was higher than the critical value in the calculation where the baffle plate becomes effective. The measured ion and neutral temperatures were $T_i \approx 0.6$ eV and $T_n \leq 0.2$ eV, respectively. More precise measurements on $T_e$, $T_i$, and $T_n$, as well as enhanced neutral pumping, will be performed for the control of the neutral density distribution to excite the drift wave turbulence.

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**References**

[1] N. Kasuya, M. Yagi and K. Itoh, J. Plasma Phys. (2006), in press.

[2] S. Shinohara, Y. Miyauchi and Y. Kawai, Plasma Phys. Control. Fusion **37**, 1015 (1995).

[3] M.Ignatenko, M.Azumi, M.Yagi, S.-I. Itoh: “Monte Carlo calculation of neutral density in Large Mirror Device”, presented at RIAM forum 2006 (Kyushu Univ., 2006) P-7.

[4] K-S. Chung, I. H. Hutchinson *et al.*, Phys. Fluids **B 1**, 2229 (1989).