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# Gyrokinetic analyses of heat transport in plasmas with different toroidal rotation profiles in JT-60U

JT-60Uにおけるトロイダル回転分布の変化に伴う熱輸送特性のジャイロ運動論コードによる解析

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In tokamak plasmas with a moderate internal transport barrier (ITB) and a weak magnetic shear, it has been found that the electron temperature ITB is steeper when toroidal rotation is in a co-direction than that when rotation is in a counter-direction. Examination of the dominant instabilities using the gyrokinetic code GS2 shows that the counter-rotation case has a more trapped electron mode than the co-rotation case. With the difference in the instability, the ratio of the electron heat diffusivity to the ion's is higher for the counter-case. The tendency agrees with the experimental result.

## 1. Introduction

Improved confinement tokamak plasmas are often associated with an internal transport barrier (ITB). The heat diffusivity $\chi$ is reduced in the ITB region, which leads to an improvement in the energy confinement. The improvement is required to forming and maintaining a high normalized beta $\beta_N$ plasma. Therefore understanding the mechanism of ITB formation is a key step towards exploring the operation scenarios in the high $\beta_N$ domain, which is one of the objectives of JT-60SA and ITER. There are a number of ITB types, and one is the "parabolic type" ITB. In plasmas with parabolic type ITB, the pressure increases smoothly starting from the ITB foot towards the magnetic axis. The parabolic type ITB is observed in both reversed magnetic shear plasmas and weak magnetic shear plasmas.[1] In these ITB plasmas, it has been found that the electron temperature ITB, $T_e$-ITB, is steeper when toroidal rotation is in a co-direction with respect to the plasma current than when toroidal rotation is in a counter-direction.[2] In this paper, to clarify the relationship between the direction of toroidal rotation and heat transport in the ITB region, we examine dominant instabilities using the flux-tube gyrokinetic code GS2 [3].

## 2. Main points of experiment

In JT-60U, the roles of toroidal rotation in weak magnetic shear plasmas with parabolic type ITB were studied using neutral beam (NB) injection. Experimental profiles for the discharge 46861 (the toroidal magnetic field $B_T$=1.6 T and the plasma current $I_p$=0.9 MA) in the co-rotating phase, $t$=9.0 s, and the counter-rotating phase, $t$=15.0 s, are shown in Fig. 1. Fig. 1(a) shows the difference in toroidal rotation profiles. As shown in Fig. 1(b), toroidal rotation in a co-direction yields a steeper $T_e$ gradient than that provided by toroidal rotation in the counter-direction.[2] The radial electric field $E_r$ profiles (Fig. 1(c)) do not have steep gradients in the core region in either case, and the safety factor $q$ profiles (Fig. 1(d)) are almost identical. But, there is a difference in the effective ion charge $Z_{eff}$: $Z_{eff}$ =3 (3.5) for the co- (counter-) rotation case. Since the power deposition profiles are almost equivalent, the difference in the $T_e$-ITB is not due to the heating power.

## 3. Analyses with GS2 code

We use GS2 [3] to examine the dominant instabilities, including the effects of collisionality and finite-$\beta$. The calculations use MHD equilibria in a G EQDSK format taken from the JT-60U database and employ three gyrokinetic species: main ions (deuterons), electrons, and a single impurity species (carbon). Fig. 2(a) shows the linear growth rates $\gamma$ and the real frequencies $\omega$ (in units of kHz). It is found that the values of $\gamma$ for the co- and counter-rotation cases are comparable in magnitude, but there is a difference in $\omega$: $\omega$ for the counter-rotation case is larger in the electron diamagnetic direction than for the co-rotation case. This means that the counter-rotation case has more

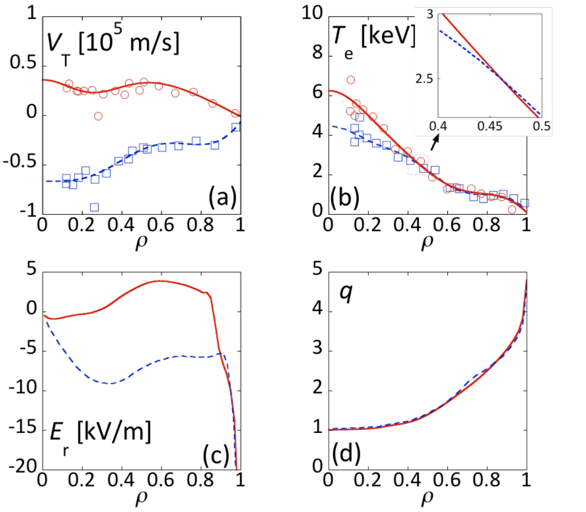


Fig.1 Comparison of profiles between the co-rotation (solid lines) and counter-rotation (dashed lines) cases for (a) The toroidal rotation velocity $V_T$, (b) the electron temperature $T_e$, (c) the radial electric field $E_r$ and (d) the safety factor $q$.

TEM-like instability than the co-rotation case. The possible candidate causing the difference in $\omega$ is the difference in $Z_{eff}$. To compare the linear calculations to the experimental result, we estimate the ratio of the electron heat diffusivity $\chi_e$ to the ion's $\chi_i$ using a quasilinear model [4] and the linear calculation results. As shown in Fig. 2(b), the value of $\chi_e/\chi_i$ is higher for the counter-rotation case than for the co-rotation case. In this figure, the solid lines are the results when using the experimental fitting parameters and the dotted lines are the maximum and minimum values when the temperature and density gradients vary by±20%. The difference in $\chi_e/\chi_i$ between the two cases agrees with the experiment. We also investigate the influence of the toroidal rotation shear on the linear growth rates, because the two cases have the different toroidal rotation shear due to the difference in their toroidal rotation profiles, as shown in Fig. 1(a). Recently, the toroidal rotation shear effect has been implemented and studied in some gyrokinetic codes. (see e.g., Refs. 5 and 6). In GS2, two effects of the rotational shear are implemented: transport suppression due to the $E \times B$ velocity shear and transport enhancement due to the parallel velocity gradient (PVG). [6] We found that the effect reduces the linear growth rate for both cases. However, the effect is not significant enough to change the tendency for $\chi_e/\chi_i$ to be higher for the counter-rotation case than for the co-rotation case.

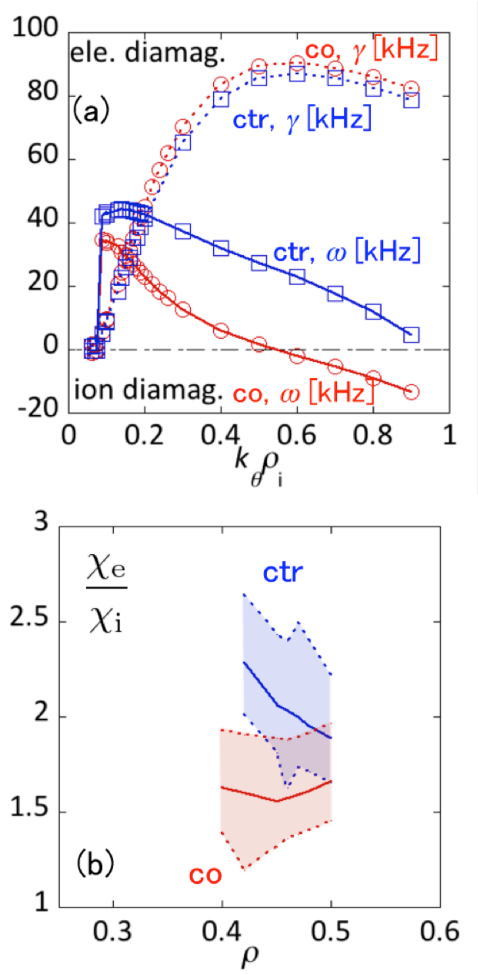


Fig.2 (a) Linear growth rates $\gamma$ and real frequencies $\omega$ at the minor radius $\rho$=0.45 as a function of normalized wavenumber, and (b) radial profiles of heat diffusivity $\chi_e/\chi_i$ ratios with error bars according to the sensitivity study.


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