23P054-P

Edge E_r structure in JT-60U H-mode having Type-I ELMs

JT-60UのType-I ELMy Hモードプラズマにおける周辺電場構造

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The first detailed measurements of radial electric field (E_r) during NBI heated ELMy H-modes in the edge of the JT-60U tokamak are reported. Depending on the direction of the external momentum input, substantial changes in not only toroidal rotation but also poloidal rotation for the carbon impurity ions are observed. The shear in the E_r becomes wider in the co-NBI, while the E_r-well becomes deeper in the counter-NBI. The relationship between E_r shear and pedestal structure at the onset of ELMs with variation in the direction of momentum input is investigated.

1. Introduction

In this study, we report the first detailed measurements of radial electric field (E_r) during NBI heated ELMy H-modes in the edge of the JT-60U tokamak, investigating the relationship between E_r shear and pedestal structure in the ion temperature at the onset of Type-I ELMs with variation in the direction of momentum input.

The E_r is determined from the radial force balance equation for the carbon impurity ions, in which the diamagnetic, poloidal velocity, and toroidal velocity terms are evaluated by means of the upgraded CXRS diagnostic having fast time resolution of up to 400 Hz with a better signal-to-noise ratio [1-2]. It should be noted that the inferred poloidal rotation velocities are based on careful consideration of the effective energy-dependent cross section and of the gyromotion of the ions, in which the apparent rotations are corrected by using the Atomic Data and Analysis Structure (ADAS) database for the C VI (n=8→7) transition.

2. Results

2.1 *Comparison of pedestal structures for co-, balanced-, and counter-NBI discharges at the onset of Type-I ELM*

As shown in Fig. 1, the shear in the edge E_r becomes wider in the co-NBI case than the ctr-NBI case, while the edge E_r-well becomes deeper in the counter-NBI case than the co-NBI case (the balanced case is roughly intermediate between them). Comparing between co- and ctr-NBI cases, the location of the Ti pedestal (shoulder) is inner in the co-NBI case with the higher Ti value [3] (an important caveat to this discussion is that the balanced case is not intermediate between them.), while the maximum |dTi/dr| values are almost similar even though the E_r structures are quite different. On the contrary, the location of the ni pedestal (shoulder) is slightly inner in the ctr-NBI case with much higher n_i value, while the maximum $|dn_i/dr|$ values seem to be correlated with the maximum $|E_r|$ and/or $|dE_r/dr|$ values. It is noted that the locations of the maxium $|dT_i/dr|$ and $|dn_i/dr|$ are close to that of the maximum $|dE_r/dr|$.

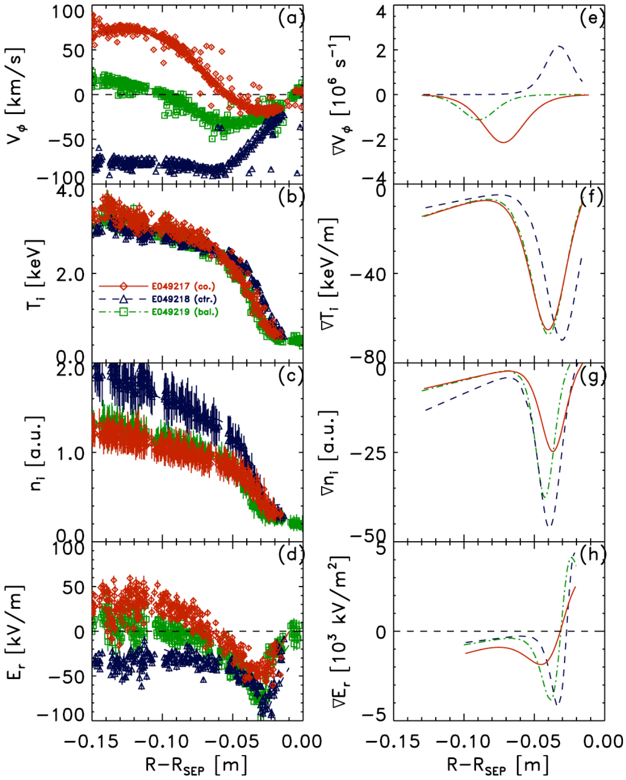

Fig.1. Profiles of (a) toroidal rotation, (b) ion temperature, (c) impurity ion density, (d) radial electric field, and (e)~(h) radial derivative of these profiles. The solid, dashed, and dash dot curves represent the results of fitting the data to a tanh-like function for co- (red diamonds), ctr- (dark blue triangles), and balanced-NBI (green squares) discharges, respectively.

2.2 *Transient transport phenomenon during an inter-ELM phase*

As shown in Fig. 2, quasi-coherent oscillations measured by reflectometer (cut-off density; 1.4×10^{19} m^{-3}) in a higher frequency range (100-200 kHz, plus broad-band one) were observed at around the E_r shear region as that seen in a weak- E_r phases in the ELM-free H-phase. It is noted that No MHD activity was seen during these frequency ranges, so that are electro-static signals. Turbulence during inter-ELM phase (~40-90% intervals of the ELM cycle) seems to be suppressed according to a formation of E_r-shear. The most interesting point is the later inter-ELM phase in the counter-NBI case, indicating an intermittent Dα drop and recovery, which is similar to the complex multi-stage "E_r transition" seen in the ELM-free H-phase [1]. However, an important caveat to this discussion is that no completely bifurcations in the edge E_r values and Da emission were observed during an inter ELM phase, so far. There is a special feature of the pedestal such as a higher density in the ELMing phase than the ELM-free phase that can be associated with different E_r transition characteristics, although the exact causality is still unclear.

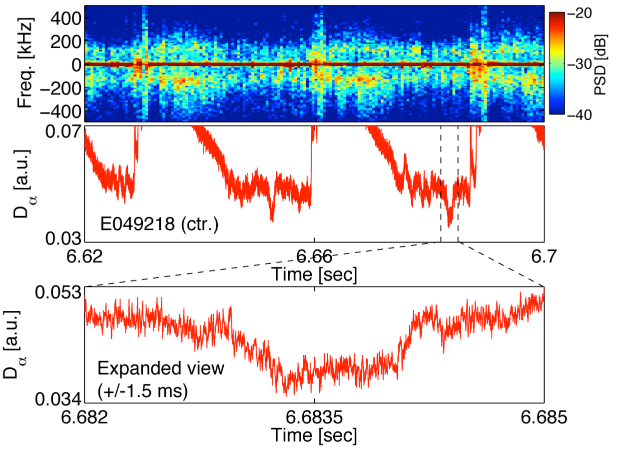

Fig.2. Contour plot of the 34 GHz reflectometry complex amplitude of the density flucutation in the ctr-NBI discharge. The Da recycling signal (and its time-expanded view) is also shown.

2.3 *E_r components*

Depending on the direction of the external tangential momentum input (co-, balanced-, and counter-NBI), substantial changes in not only toroidal but also poloidal flows for the carbon impurity ions are observed at around the E_r-well region near the bottom half of pedestal (at around $R\text{-}R_{SEP} \sim -0.04$m), maintaining radial force balance. It is noted that the poloidal flow for the carbon impurity ions from the middle to the top of pedestal seems to be damped, while the toroidal flow is accelerated toward the direction of the torque, contributing to the different E_r structures. As a result, the shear in the edge E_r becomes wider in the co-NBI case, while the edge E_r-well becomes deeper in the counter-NBI case. Thus, the E_r shear is enhanced in the co-NBI case after E_r transition, which occurs in a very narrow region at around $R\text{-}R_{SEP} \sim -0.025$m, while the onset condition for the E_r transition may be more easy in the ctr-NBI, if the E_r (or Poloidal Mach number, $U_{p,m}$) value itself is critical one.

Effect of other external momentum source on Er structure (such as perpendicular NBI) is also discussed. Applying the perpendicular injected beams, there could be a significant radial current due to direct orbit (and/or ripple) losses of fast ions, which could lead to significant torque on the plasma edge region. Recently upgraded OFMC (Orbit-Following Monte-Carlo) code, which is capable of estimating both the jxB and collisional torques [4], is a powerful tool to elucidate the origin of the electric field in a plasma during the NBI heating with various momentum sources, since there are basically three "knobs" (diamagnetic drift, poloidal and toroidal rotations) affecting the radial electric field. As a result, the jxB torque is found to contribute to a negative E_r structure at the plasma edge region, depending on the momentum injection angle. Some of the uncertainties in these results are also discussed, and directions for future work to verify the paradigm of ExB shear suppression of turbulence will be described.

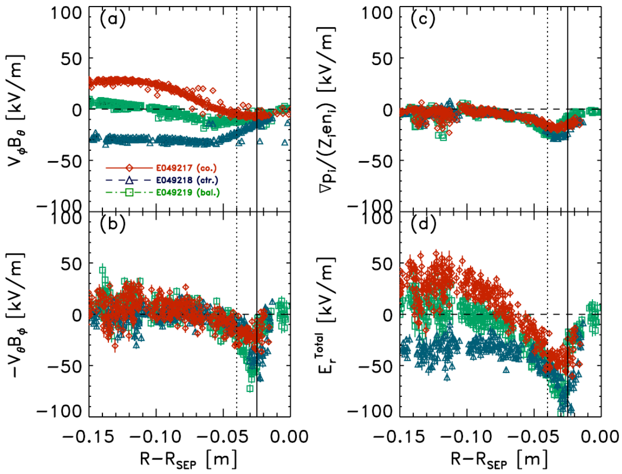

Fig.3. Radial profiles of the Er components. (a) toroidal rotation term, (b) poloidal rotation term, (c) diamagnetic term, and (d) total Er.

References

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