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Toroidal rotation driven by electron temperature gradients in CHS plasmas

Toroidal rotation anti-parallel to the co-direction of neutral beam injection (NBI) has been observed in the Compact Helical System (CHS) when a 106-GHz second harmonic electron cyclotron heating (ECH) pulse was applied to an NBI-heated plasma with an electron density below 0.7×10^{19} m^{-3}. This toroidal rotation is associated with a large poloidal rotation, a large positive electric field (>10 kV/m), and a steep electron temperature gradient. This toroidal flow in the counter-direction can be explained as a flow along the minimum ∇B direction, driven to be consistent with the sign of the radial electric field E_r.

This reversal of toroidal flow is observed only when an ECH pulse is applied to an NBI plasma with low electron density ($<0.7 \times 10^{19}$ m^{-3}). The target plasma is produced by an ECH pulse, and the neutral beam is injected from 40 to 200 ms. Figure 1 shows the electron temperature, density, and poloidal and toroidal rotation velocities for a discharge where reverse toroidal rotation was observed during the second harmonic ECH pulse. Plasma parameters for discharges without second harmonic ECH are also plotted as a reference.

With second harmonic ECH, the electron temperature increases to 2 keV (hot electron mode), while it is only 0.2 keV when there is no second harmonic ECH pulse, as seen in Fig. 1(a). The electron density drops from 0.5×10^{19} m^{-3} to 0.3×10^{19} m^{-3} after the second harmonic ECH pulse is applied, even with a constant gas puff, because of pump-out by the ECH. On the other hand, when there is no second harmonic ECH pulse, the electron density tends to increase in time even without gas puffing (which is turned off at the start of NBI at t = 40 ms). During the second harmonic ECH pulse, the electron collisionality is low enough to cause the plasma potential to be on the electron root (positive electric field E_r). The positive electric field during the second harmonic ECH pulse is confirmed by measurements made with the heavy ion beam probe (HIBP) and poloidal rotation velocity in the ion diamagnetic direction measured with charge-exchange spectroscopy [Fig. 1(b)]. A large electric field, 10–20 kV/m, and large poloidal rotation velocity, 10–20 km/s, are produced near the plasma center (ρ = 0.3), where the steep temperature gradient is observed [Figs. 1(d) and (e)].

The neutral beam is tangentially injected into the plasma in the co-direction. Here the co-direction (positive rotation velocity) is defined as parallel to the equivalent toroidal plasma current, while the counter-direction (negative rotation velocity) is defined as anti-parallel to the equivalent toroidal plasma current. As seen in Figs. 1(c) and (f), when there is no second harmonic ECH the plasma rotates parallel to the NBI because of the toroidal momentum from the NBI. However, when the second harmonic ECH is turned on, the plasma rotation in the co-direction decreases and finally the plasma rotates anti-parallel to the NBI.

These measurements show the self-generated toroidal rotation associated with large poloidal rotation (large positive E_r) during a second harmonic ECH pulse. In CHS, the direction of the self-generated flow is anti-parallel to the co-direction for positive E_r, while it is parallel to counter-direction for negative E_r. Note that the flow anti-parallel to the co-direction contributes to negative electric field.

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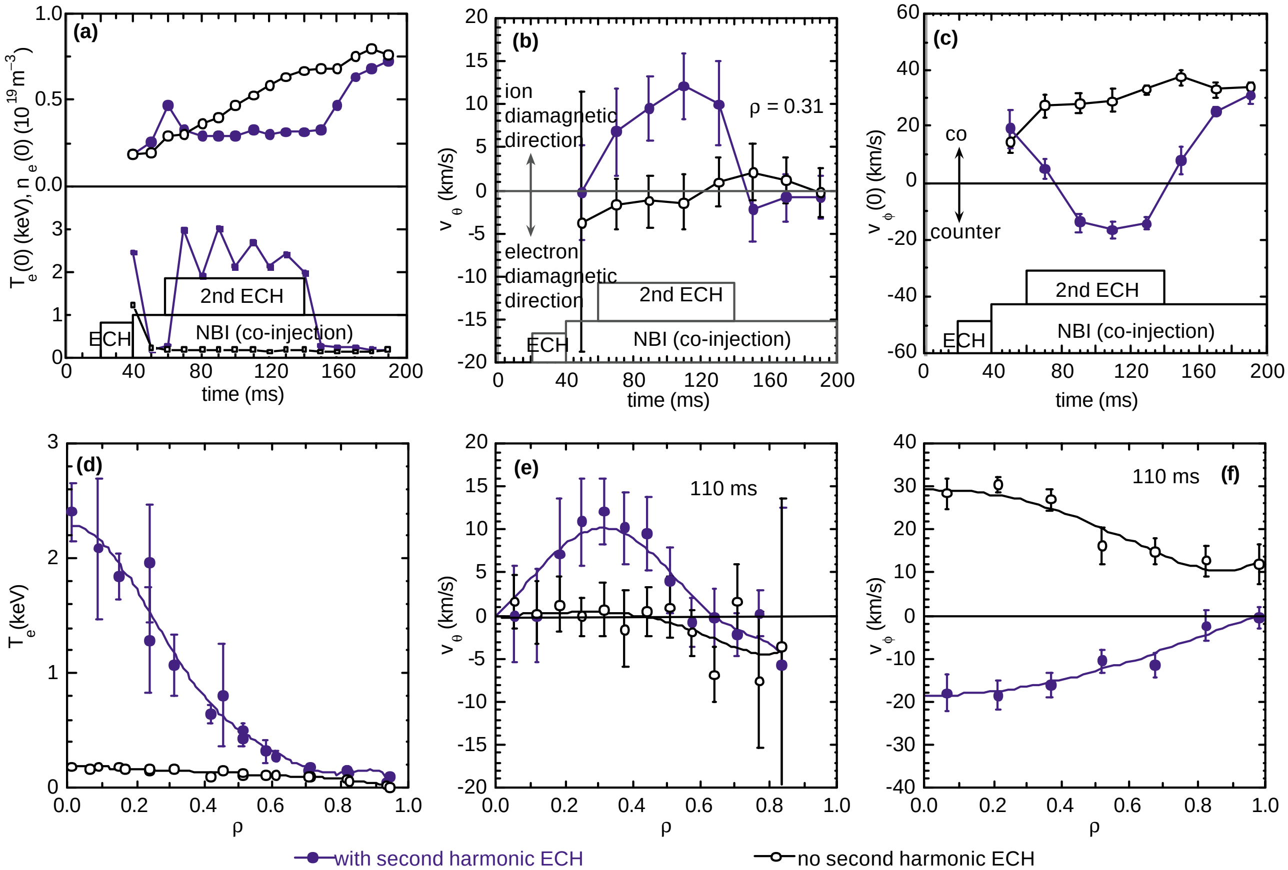

Fig. 1. Time evolution of (a) central electron temperatures (squares) and density (circles), (b) poloidal rotation velocity at ρ = 0.38, and (c) central toroidal rotation velocity; (d) radial profiles of electron temperature averaged over 70–140 ms; (e) poloidal rotation velocity at *t* =110 ms; (f) toroidal rotation velocity at *t* =110 ms. In each case, solid circles identify discharges with second harmonic ECH; open circles, discharges without second harmonic ECH.

Therefore, when E_r becomes positive, a toroidal rotation that reduces the positive electric field is driven in CHS. This is in contrast to the effect of toroidal flow in tokamaks, which enhances the radial electric field. (When the radial electric field becomes negative, plasma rotation in the counter-direction is enhanced.)

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