EFFECT OF PFIRSCH-SCHLÜTER FLOW ON TOROIDAL FLOW IN THE EDGE REGION OF ADITYA-U TOKAMAK

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Simultaneous measurements of intrinsic toroidal (v_ϕ) and poloidal rotation (v_θ) from the Doppler's shift of C^{2+} ions (at 464.74nm) has been performed to reveal the underlying physical mechanism behind these self-generated flows observed in ADITYA-U tokamak. In the previous study [1], it was found that the edge V_ϕ of C^{5+} ions (at 529nm) in ADITYA-U is driven by $E_r \times B_\theta$ drift, which damps from ~ +7km/s (co-current) to almost zero velocity on increasing the edge electron density (n_e). In the recent study (done with C^{2+} ions), similar behavior of edge V_ϕ damping is observed with increasing edge n_e. Interestingly, further increment in the edge density triggered the edge rotation reversal, making the flow in counter-current direction (with a velocity of ~ -6km/s). Apart from V_ϕ, direction reversal of edge poloidal rotation V_θ is also observed with the edge n_e. In order to understand the fundamental nature of these self-generated flows (intrinsic V_ϕ & V_θ) in ADITYA-U, the direction of plasma current (I_P) as well as of toroidal magnetic field (B_T) are deliberately reversed in one of the operation campaign. Usually, I_P and B_T (when seen from top) in ADITYA-U is in clockwise and anti-clockwise direction respectively (as shown in figure 1), which will be referred as scenario-1 in this paper. While the scenario-2 consist of the discharges taken after reversing: I_P and B_T (both simultaneously), such that I_P and B_T becomes anti-clockwise and clockwise respectively (when seen from top). The experimental setup for measuring toroidal and poloidal rotation is well explained in references [1-3].

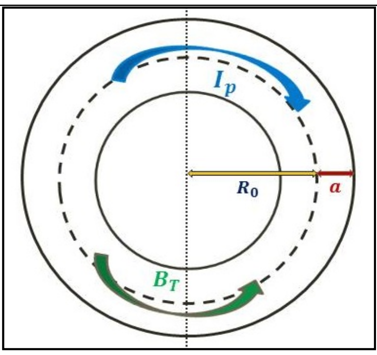

Fig 1: Scenario-1: Direction of plasma current (I_P) in clockwise and toroidal magnetic field (B_T) in anti-clockwise direction (when seen from top).

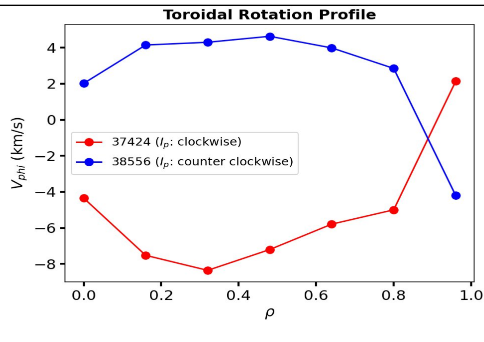

Fig 2: Chord weighted toroidal rotation profiles for scenario-1 (Shot# 37424) & scenario-2 (Shot# 38856) discharges are plotted in red & blue respectively.

For both: scenario-1 & 2 discharges, theoretical values of edge rotation V_ϕ is calculated and compared with the experimental values. Residual stress, a well known candidate for generating V_ϕ can produce a co-current edge

V_ϕ of ~ 3-4 km/s in ADITYA-U, which matches quite well with the experimental values in the low edge density range. Another theoretical model, given by Hirshman and Sigmar (neo-classical approach) predicts an co-current edge V_ϕ of ~ 4-5 km/s, which again matches quite well with the experimental values in the low edge density regime. However, in the high edge density regime, the experimental edge V_ϕ becomes counter-current in both the scenarios, resulting in a mismatch with the theoretical values (in term of sign).

Apart from the residual stress, the radial electric field can also generate intrinsic toroidal rotation in a tokamak. The E_r required to produce the toroidal rotation (when poloidal rotation and diamagnetic drift contributions are negligible) is given by the following equation:

$$V_\phi = E_r / B_\theta \qquad (1)$$

Since, all the plasma parameters (except the direction of I_P and B_T) are kept constant in both the scenarios, the E_r must remain unaltered during both scenarios. So, with the help of equation-1, the flip observed in V_ϕ profile (in figure 2) can be understood from the directional change of B_θ (caused by reversing I_P direction in scenario-2). In figure-2, chord weighted V_ϕ profile for two discharges, each from both scenarios are shown. It can be clearly seen that the direction of V_ϕ (in tokamak frame of reference) flipped its sign while I_P & B_T configuration is switched from scenario-1 to scenario-2. This indicates that the residual stress is not driving the intrinsic toroidal rotation in ADITYA-U, otherwise this flip, shown in figure-2, would not have been observed. The overall intrinsic toroidal rotation in ADITYA-U is so driven mainly by the $E_r \times B_\theta$ drift only. However, the magnitude of edge V_ϕ generated by the residual stress matches well with the experimental values (in the low edge n_e regime). Similarly, the Hirshman and Sigmar approach also suggests a very good agreement with the observed V_ϕ (at low edge density) in both the scenarios, but it again also fails to explain the observed counter-current rotation in both scenarios. In figure 3, edge V_ϕ is plotted in the two scenarios w.r.t brightness value (brightness is a spectroscopic measurement which varies linearly with the edge density).

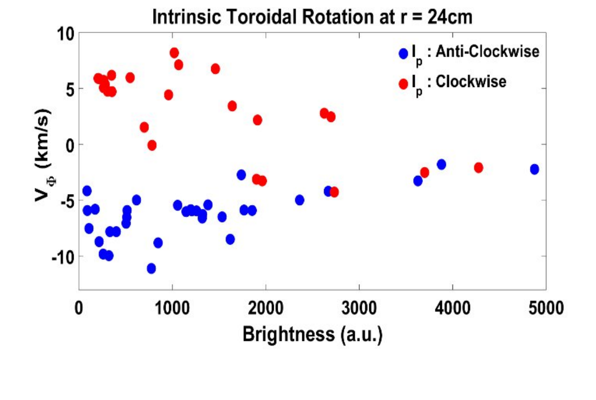

Fig 3: Figure depicts the variations in the toroidal rotation measured at r=24cm w.r.t to Brightness values (density like parameter) at r=24cm for: scenario 1 (in red), scenario 2 (in blue).

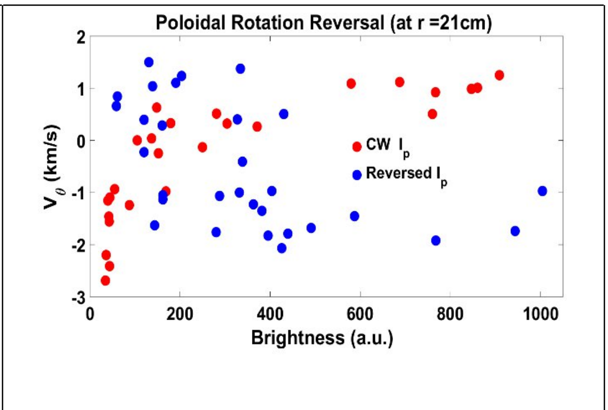

Fig 4: Figure depicts the variations in the poloidal rotation measured at r=21cm w.r.t to the Brightness values (density like parameter) at r=21cm for: scenario 1 (in red), scenario 2 (in blue).

Apart from the V_ϕ, edge V_θ is also observed to reverse its direction with an increase in the edge density. Figure 4 exhibits the V_θ flipping its sign during scenario change, which again suggests the key role $E_r \times B_\theta$ drift, along with the Pfirsch-Schlüter flow in driving the edge poloidal rotation in ADITYA-U tokamak. This flipping in the direction of poloidal rotation is caused due to the fact that reversing the toroidal magnetic field B_T from scenario 1 to 2, causes a directional change in grad-B drift. As a result, the direction of Pfirsch-Schlüter flow (due to the charge separation) along with the $E_r \times B_\phi$ flow gets reversed, which ultimately reverses the direction of poloidal rotation observed in the edge region of ADITYA-U tokamak. Both the toroidal and poloidal flows in ADITYA-U are affected by Pfirsch-Schlüter flows.

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