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Formation of the radial electric field profile in WEST tokamak

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The shear of the radial electric field at the edge is widely accepted to be responsible for turbulence reduction in edge transport barriers and thought as a key ingredient of the improved confinement of H-mode plasmas. Nevertheless, a full understanding of how its profile builds up at the edge is still lacking. It can either be formulated as the result of a competition between several mechanisms that generate and damp flows or as the result of a non-ambipolar particle flux, which enhances radial charge separation imposing a radial electric field profile. Among possible mechanisms, one can think of turbulence generated flow via Reynolds stress, ion orbit losses, toroidal magnetic ripple and the effect of neutral friction at the edge. Based on previous results obtained on Tore Supra, the radial profile of the perpendicular flow expected in WEST can be separated in three spatial areas. Inside $\rho = 0.8$, the radial electric field is dominated by losses of thermal ions in the magnetic ripple (1) while between $0.7 < \rho < 0.95$, a competition between this latter and the generation of large scale flows by turbulence appears as a possible explanation of the measured poloidal asymmetry of the mean perpendicular velocity (2). In addition, edge conditions such as contact points and parallel dynamics in the scrape-off-layer (SOL) influence the edge profiles beyond $\rho = 0.9$ (3). This contribution presents unexpected differences in the radial electric field profile observed in WEST between Lower Single Null (LSN) and Upper Single Null (USN) configurations and a study of the competition between specific mechanisms playing a role in the formation of this profile.

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WEST is a large aspect ratio machine $(A = 5 - 6)$ with a high level of magnetic ripple around 3% at the plasma edge, symmetric divertors, producing RF heated plasmas (using both Low Hybrid and Ion Cyclotron Resonance Heating systems) with active X-point either at the bottom or at the top and a $B \times \nabla B$ drift always pointing down (as visible in Fig.1). In the context of H-mode scenario development, measurements of the $E \times B$ velocity using Doppler Backscattering system (DBS) in LSN configuration exhibits radial profiles with a well just inside the separatrix. This shape appears similar to standard observations in tokamak plasmas : a positive velocity outside the separatrix, changing sign across the separatrix forming a well in the edge of the confined plasma.

Comparing the radial profiles of the $E \times B$ velocity between LSN and USN plasmas in L-mode regime shows an impressive difference : the radial profile for USN does not contain a well and exhibits a smooth decay from the edge to the core (see Fig.1). This tendency is consistent with the fact that the configuration with the $B \times \nabla B$ drift pointing toward the active X-point, designated as the “favorable configuration”, is more favorable to reach the H-mode as compared to the opposite case when $B \times \nabla B$ drift points away from the active X-point. Nevertheless, there are multiple proposed explanations without a clear consensus on the reason of such favorable versus unfavorable configuration and systematic experimental comparisons of velocity profiles in USN and LSN are scarce. Regarding the results from the Fig.1, the WEST tokamak emerged as a particularly interesting machine to study this difference since it appears exacerbated between these two configurations.

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In this spirit, experiments have been performed to compare the DBS velocity profiles at the edge in both USN and LSN in different plasma conditions. Among the results, it is found that the plasma current impacts significantly the velocity profile in the USN discharges (Fig.2). At low current, the $V_{E\times B}$ profile does not exhibit a well but a slow decay leading to the striking difference with the LSN discharges. When increasing the plasma current, the $E \times B$ velocity starts to form a well to end up with a deeper profile than in LSN at high current. Indeed, in LSN configuration, the increase of the plasma current also deepens the radial electric field well ; however, the effect is less pronounced than in USN and the profile shape remains similar. Interestingly, for fixed plasma current and moderate to high heating power, the velocity profile ends up deeper in the USN configuration for same plasma conditions.

This result leads to an unexpected situation in which the "unfavorable configuration" seems more favorable, at least from the point of view of turbulence shearing. Conjointly, the dynamics of the density fluctuations measured with DBS is clearly affected in the inner branch of the velocity well in the case of USN while not in the case of LSN discharge.

The influence of the edge topology on the radial electric field has been addressed numerically using the gyrokinetic GYSELA code in which a limiter, modelled through a penalization technique, is placed at the bottom or at the top of a circular plasma (4). Figure 3 shows the resulting $V_{E\times B}$ velocity obtained in such simulations. The radial profile is found in qualitative agreement with the experiments, with a negative velocity in the confined region about few km/s. The presence of the limiters is associated with the formation of a well in the profile near the separatrix. In addition, the depth of the well is found to be sensitive to the edge configuration and limiter position as observed in both Tore Supra and WEST tokamaks. The shear layer appears related to both ion orbit loss through the separatrix and vortex-flow interaction. The difference between both configurations is studied regarding the sign of the Reynolds stress terms coming from magnetic shear and radial electric shear tilting.

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In summary, in WEST, the shape of the radial electric field profile is found to strongly depend on the magnetic configuration. Changing the plasma conditions, such as plasma current, density, heating power, appears to modify the balance between mechanisms playing a role in the formation of the radial electric field. In USN, the profile evolves from an "unfavourable" shape, without any well, to a strongly sheared shape when increasing the plasma current or the heating power while in LSN the velocity profile appears less sensitive to such plasma conditions. The USN/LSN difference is captured by first-principles simulations including core-edge coupling with neoclassical and turbulent physics.

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Country or International Organization

France

Affiliation

Laboratoire de Physique des Plasmas, CNRS

Author: VERMARE, Laure (CNRS, LPP Ecole Polytechnique)

Co-authors: PERET, Mathieu (IRFM, CEA Cadarache); DIF-PRADALIER, Guilhem (CEA, IRFM, F-13108 Saint--Paul-lez-Durance cedex, France); HENNEQUIN, Pascale (LPP, CNRS); GUNN, James Paul (CEA Cadarache); GARBET, Xavier (CEA); ARTAUD, Jean-Francois; GURCAN, Ozgur (LPP/Ecole Polytechnique/CNRS); BOURDELLE, Clarisse (CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France.); CLAIRET, Frederic (CEA); Dr FEDORCZAK, Nicolas (CEA, IRFM, Saint Paul Lez Durance, France); HONORÉ, Cyrille (LPP); GRANDGIRARD, Virginie (CEA/IRFM); MORALES, Jorge (IRFM, CEA Cadarache); SARAZIN, Yanick (CEA, IRFM); VARENNES, Robin (CEA.IRFM); VEZINET, Didier (IRFM, CEA Cadarache); WEST TEAM (CEA/IRFM)

Presenter: VERMARE, Laure (CNRS, LPP Ecole Polytechnique)

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