## §1. Comprehensive Investigations on Dynamics of Magnetic Field in Fusion Plasmas and its Influence on Turbulence Structure

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For the comprehensive understandings of transport phenomena in toroidal confinement systems and improvement of the predictive capability of burning plasmas in ITER, the impact of magnetic shear and $T_e/T_i$ ratio has been extensively investigated in LHD for comparison with the results of tokamak experiments [1], such as in JET and JT-60U[2], using the international database described in Ref. [3]. The intrinsic advantage of magnetic shear for the transport reduction has been often obscure partly due to the interplay of MHD but occasionally highlighted out of the shadow in tokamaks. In particular, spontaneous ITB formation in the $T_e$ profile has been pervasively recognized in tokamaks under the negative shear. In addition, conventional linear models proposed to date consider that the magnetic shear influences the growth rate of turbulence and accordingly the anomalous transport for the ITG turbulence [4]. On the other hand, Ref. 5 suggests a combination of three different stabilizing mechanisms, namely the density peaking, **E** x **B** shear and magnetic shear, based on the drift wave stability calculations. In order to extract the magnetic shear contribution out of various parametric dependences, a series of dedicated experiments has been designed and performed in LHD, where inherently negative shear is modified solely by the tangentially injected beam driven current. The direction of tangential nNB injection was thereby switched from co to ctr and vice versa at different densities and $T_e/T_i$ values under the sustained heating power in the experiment. The influence of the modification in the local magnetic shear has been extensively investigated in terms of the changes in the kinetic profiles. In addition, the perpendicular pNB has also been applied at various densities for the ion heating to elucidate the involvement of $T_e/T_i$ ratio. Furthermore, perturbative transport analysis has also been performed using pellet and modulated ECH.

As one of the major experimental difficulties in extracting the magnetic shear contribution out of the transport characteristics is to waive the MHD effect, we have adjusted the position of magnetic axis $R_{ax}$, aiming at relocating the malign rational surface out of the core region. As a result, an abrupt reduction in $dT_e/d\rho$ was observed when $\iota$= 0.5 surface resides in the low shear region for the $R_{ax}$=3.6m case. For discharges with larger $R_{ax}$ of 3.75m, which is less vulnerable to MHDs, due to the extended magnetic well structure over half the minor radius, no sign of apparent MHD was observed in the magnetic probe signals. The result of low-n ideal interchange mode stability analysis indicates $dT_e/d\rho$ abruptly decreases as the normalized growth rate crosses the critical value of $10^{-2}$ under reducing magnetic shear in the case of $R_{ax}$=3.6m, whereas the reduction of the shear results in the disappearance of the $\iota$= 0.5 surface in the $R_{ax}$=3.75m case. Accordingly, $R_{ax}$ =3.75m was chosen throughout the rest of the campaign, and extended experiment has been performed with the long pulse nNB.

Although, the flattening of iota profiles was observed i.e., the iota value is substantially changed from 0.18 to 0.84 in the core region at $\rho$=0.28, $T_e$ and $T_i$ profiles both indicate subtle changes. The $T_e/T_i$ ratio remained at around 2, since the absorption power of nNB would be larger than that of pNB in this density regime of $\sim 6\times10^{18}m^{-3}$. The moderately increasing density in the core region, due to the pNB fuelling, turns to decrease after the nNB is switched from co- to ctr-direction, as a result of the changes in the deposition profile. However, the gas puffing efficiently supplies particles in the outer region, and the profile shape itself in the core region does not vary substantially as a whole without the apparent changes in the $n_e$ gradient. Indeed, not only the equilibrium but also $L_n$, $L_T$ and $T_e/T_i$ are sustained at nearly constant values within a few percent during the magnetic shear modification. It was confirmed that the electron thermal diffusivity stays around (5-10) $m^2/s$ and remains roughly the same, which is consistent with the subtle changes in the profile shape. In regard to the perturbative analysis, only transient reduction in the local diffusivity was observed when the magnetic shear was reduced. Therefore, it may be conjectured that the turbulence structures are different in tokamaks and helical devices, and common features are indeed hard to find.


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