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Dynamical coupling between parallel flows and radial turbulent transport in a linear plasma machine

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1. Introduction

The mechanisms underlying the generation of plasma flows play a crucial role to understand transport in magnetically confined plasmas[1,2]. When the shearing rate approaches the characteristic frequency of the turbulence, a reduction in the turbulence amplitude is predicted. The best performance of existing fusion plasma devices has been obtained in plasma conditions where $E \times B$ shear stabilization mechanisms are likely to play a key role: both edge and core transport barriers are related to a large increase in the $E \times B$ sheared flows. Although sheared flows play a key role in reducing plasma transport in fusion plasmas, recent experiments in Q - devices[3] have investigated the development instabilities excited by parallel sheared flow velocity.

The possible link between turbulence and flow generation have been discussed both from the theoretical and experimental point of view. Sheared flow can be generated when turbulence driven flows play a dominant role in the momentum balance. In this case, sheared perpendicular flow is expected to increase when the turbulent energy is large enough to overcome the flow damping.

Recent experiments[4,5], have suggested that turbulence can drive parallel flows which might (at least partially) explain the magnitude of the measured flows. This paper reports experimental evidence of parallel flows dynamically coupled to radial turbulent transport in a linear device.

2. Experimental Setup

The plasma is generated in a cylindrical glass vessel with an internal diameter of 0.07 m and a length of 1 m (see Fig. 1). The vessel is located inside a circular waveguide of 0.08 m in diameter. A magnetized plasma is produced by launching longitudinally (LMG) electromagnetic waves with a frequency $f = 2.45$ GHz. The incident power (P_{LMG}) is in the range $0.6 \text{ kW} < P_{\mathrm{LMG}} < 1.2 \text{ kW}$ and the system can operate in a continuous regime. The stationary longitudinal magnetic field ($0.05 \text{ T} < B_0 < 0.15 \text{ T}$) is generated by six-water cooled coils, which are concentric with the waveguide. Measurements reported in this paper were performed for Helium plasmas with a magnetic field B_0 = 0.12 T. The mean electron density is determined using an 8 mm interferometer. An array of Langmuir/Mach probes provide local value of electron density, floating potential and Mach numbers as well as their fluctuations along the whole plasma radial column.

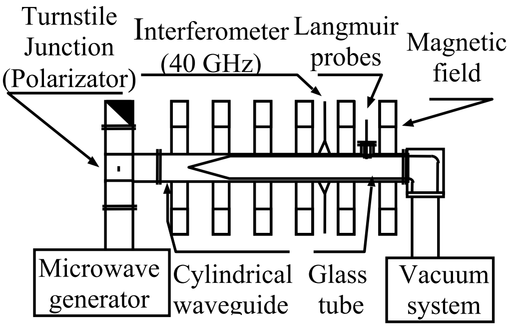

Figure 1. Scheme of the Linear Plasma Machine

Electron density typically ranges from 10^{15} m^{-3} to 10^{18} m^{-3}. Electron temperatures are in the range 5 – 30 eV. Normalized fluctuations of electron density are in the order of 20% in the inner plasma region, increasing in the outer region (typically below 50%). Radial fluctuations of floating potential $e\Phi_{rms}/kT_e$ are below 5% along the whole plasma column.

3. Experimental results

The fluctuation induced particle flux has been computed from the correlation between density and poloidal electric field fluctuations $\Gamma = \langle \tilde{n}_e \tilde{E}_\theta \rangle$ neglecting the influence of electron temperature fluctuations. The resulting transport is in the order of 10^{19} m^{2}s^{-1} and radially outward, being maximum around $r = (1.5 - 2)$ cm. Using the model of Hutchinson[6] the Mach number of the axial plasma flow was deduced from the ratio of upstream and downstream ion saturation current: M = 0.4 ln(I_{up}/I_{dw}). Subsonic flows ($0 < M < 0.5$) are found in the plasma. A radial profile of fluctuation induced flux and parallel flow is shown in figure 2.

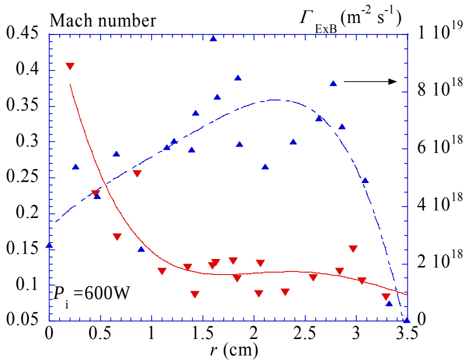

Figure2. Radial Profile of Mach Number and $\Gamma_{E\times B}$

In order to study the dynamical coupling between parallel flows and induced fluctuations transport, we have computed the expected values of Mach number at different values of induced turbulent fluxes as:

$$E\left[Mach/\Gamma_j\right] = \sum_i P_{ij} M_i \Big/ \sum_i P_{ij}$$

where P_{ij} is the probability that at a given instant, M_i and Γ_j occur simultaneously, and represents the average value of the probability distribution of M at a given value of Γ[7]. Figure 3 represent the expected value of the parallel Mach number for a given turbulent transport for four different radial positions in the plasma. The results show a clear dynamical coupling between both magnitudes. The dynamical coupling shows different behaviour at different plasma radius. Typically, for *r* < 1 cm has parabolic shape with a broad maximum around zero flux. For r = (1 - 2) cm the curve is rather flat. In the external part of the plasma *r* > 2 cm the coupling shows parabolic curves with a minimum around $\Gamma = 0$.

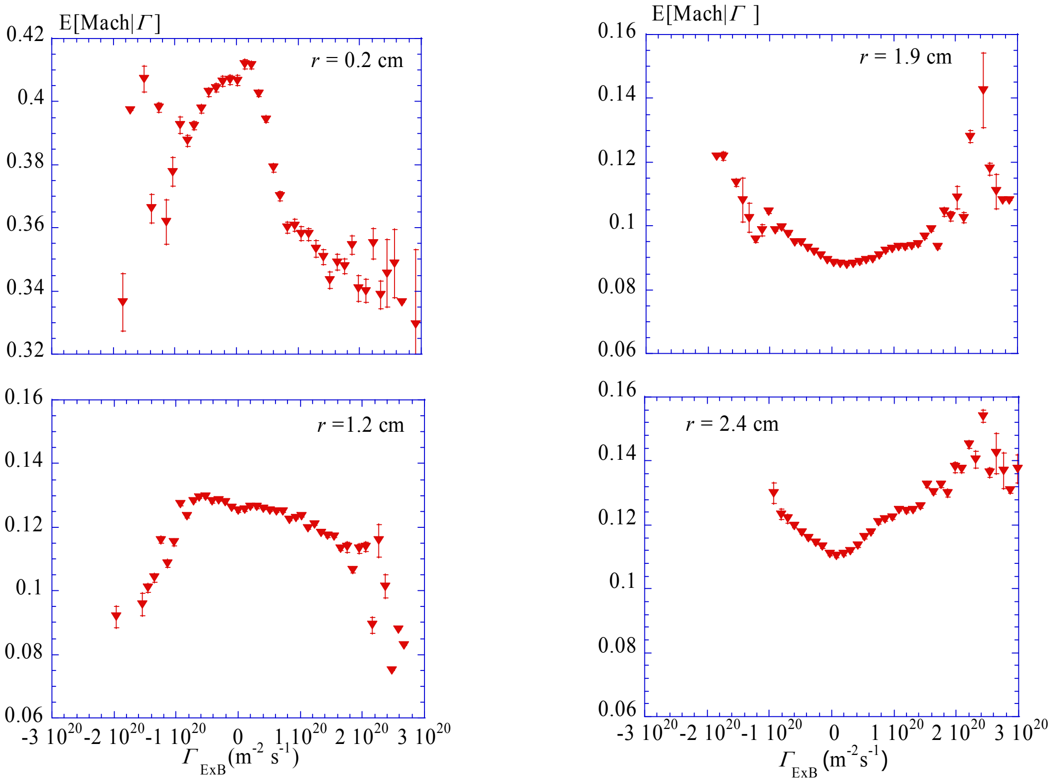

Figure 3. Expected number of parallel Mach number versus local transport for different radii

The behaviour of this dynamical coupling with the microwave incident power has been investigated. In figure 4 we show the measured Mach number for three different radial positions as a function of the incident power. Averaged Mach numbers change with incident power, becoming in some cases (r = 0.4 cm, P_i = 1000W) negative. Besides, the shapes of the expected Mach numbers can be significantly modified as the incident power increases.

4. Discussion and conclusions

Present results shows that parallel (parallel flows) and perpendicular ($E \times B$ transport) dynamics are connected in a linear device. Furthermore, the degree of coupling as well as the shape of the joint probability distribution function changes radially and also depends on plasma conditions (like heating).

Different mechanisms are candidates to explain these findings. First it should be noted that in the plasma region (r ≈ 1 cm) gradients in the parallel velocity are comparable (and even

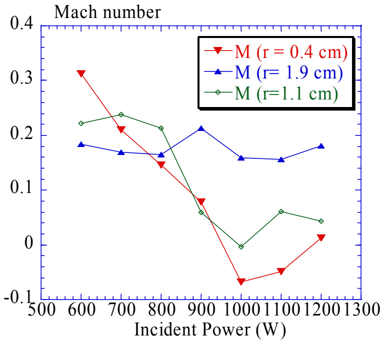

Figure 4. Mach number versus incident power

larger) than the density scale length. In fact, the parallel velocity shear is close to the threshold condition for Kelvin-Helmholtz instabilities [$dM/dr \approx c_s^{-1} dv_{parallel}/d_r \approx L_n^{-1}$]. Then, instabilities driven by parallel sheared flows can affect both parallel dynamics and radial transport, providing a physics mechanism to explain present findings. Indeed, it should be mention that instabilities driven by parallel sheared flows have been already identified in Q- devices[3]. An alternative mechanism can be connected with interchange of energy between turbulence and flows. Several theoretical works pointed out the importance of Reynolds stress[8,9], as a way to interchange energy between the different scales presented in the plasmas. Present results resemble recent experiments carry out in fusion plasmas where it have been point out that parallel flows are affected by turbulence. Actually, a dynamical coupling between parallel dynamics and $E \times B$ turbulent transport has been reported in the plasma periphery of JET tokamak, showing that the degree of coupling also changes radially in the plasma and depends on plasma conditions.

Experimental results show that the dynamical coupling between transport and flows shows differences at different plasma radii, suggesting that the coupling between transport and flows depends on the proximity to the naturally occurring parallel velocity shear layer.

Finally, experimental results presented in this paper suggest that although turbulence can be considered as quasi bidimensional in magnetized plasmas, parallel dynamics might still play an important role in the regulation of radial transport as recently pointed out in turbulence simulation in toroidal plasmas[10].

Acknowledgments

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[1] Burrel K. 1999 *Phys.Plasmas* 6 4418
[2] Terry P.W. 2000 *Rev. Mod. Phys.* 72 09
[3] Kaneto T. et al .2003 *Phys. Rev. Lett.* 90 125001
[4] Hidalgo C et al. 2004 *Phys. Rev.E* 70 067402
[5] Lamborbard et al. 2004 *Nuclear Fusion* 44 1047
[6] Hutchinson I.H. 1988 *Phys. Rev. A* 37 4358
[7] Gonçalves G. 2002, Nuclear Fusion 42 1205
[8] Carreras B. A. et al.1991, *Phys. Fluids* B 3 1438
[9] Diamond P.H. et al. 1991 *Phys. Fluids* B 3 1626
[10] Hallatschek K. 2004 *Phys. Rev. Lett.* 93 065001