Effect of finite vertical field on plasma profiles and dynamics of density structures in simple toroidal device 'Thorello'

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Introduction

The effect of vertical field, i,e, influence of variation in ratio of toroidal ($B_\emptyset$) to vertical magnetic field (B_z) and hence reduction in connection length on mean and fluctuation profiles is investigated in a simple magnetized torus (SMT), THORELLO. A SMT is a low temperature device without rotational transform in which plasma is typically confined purely by toroidal field [1-3]. The device is a good test bed to study turbulence, transport, and instabilities in toroidal geometry which have features very similar to that of edge plasma of fusion devices. SMTs have typical densities and temperatures an order of magnitude less than that of tokamak edge plasma; their plasmas are subjected to both gradient and curvature in magnetic field. This offers a unique opportunity to study one of the major convective transport in fusion device in fusion devices, namely transport by intermittent blob filaments with adequate spatial and temporal resolution which is limited only to a small area in fusion devices [4]. On the other hand, $\boldsymbol{E_z} \times \boldsymbol{B}$ drift induced by gradient and curvature in magnetic field prevent the system to be in equilibrium, where E_z is the vertical field arising from charge polarization. Recently, it is shown that, in SMT device TORPEX with ECR plasma source, a quasi-stationary equilibrium can be established by the application of finite B_z to the toroidal one ($B_\emptyset$) where the resulting helical field limit the E_z by short circuiting parallel current [5]. On the other hand, unlike SMT with wave injected plasma, presence of limiter and substantial radial electric expected to enhance the short-circuiting effect by plasma rotation in SMT device with thermionic discharge. But no such observation is reported yet. In this work, we show the effect of vertical field B_z on plasma, fluctuation profile and spatio-temporal structures on an SMT device with plasma produced by thermionic discharge. Further, the study is more interesting due to the fact that fundamental features of spatio-temporal structures and statistical feature primarily depend on plasma source where charge and mass current induced by localized source in thermionic discharge plays a different role.

Experimental setup and results

Experiments presented in this work is performed in a simple magnetized torus THORELLO having a major radius (R_0) of 40 cm and a minor radius (a) of 8.75 cm located at University of

Milano-Bicocca [6]. A set of 56 toroidal field coils are used to produce a maximum achievable toroidal field of 0.2 T and the vertical field is applied using two horizontal coils in Helmholtz arrangement with each coils having a radius of 80 cm. Plasma source consists of three braided tungsten wires (a= -20 mm, z= 20 mm) each having a diameter of 0.75 mm and length of 30 mm, biased negatively (-90 V) with respect to the limiter. The present experiment is performed at a toroidal field of 40 mT and vertical field is varied between 0 mT and 0.7 mT for a fixed working pressure of $4 \times 10^{-4} mbar$. Diagnostics were carried out using electrostatic Langmuir probe. 2D measurements from the complete poloidal section is obtained using an L-shaped scan probe by means of radially moving and rotating along its axis using a stepper motor-controlled probe drive and 1 D measurements obtained using another probe fixed in an oblique port. The variation in connection length (L_c), pitch ration (r_B), pitch (Δ) and number of field line turns (N) when B_z is varied from 0 to 0.7 mT, i.e, from closed to open field line configuration is shown in the table below. Here $L_v = 17\ cm$ is the height of the device.

B_z (mT)	0	0.3	0.4	0.5	0.6	0.7
$L_c = 2a(B_\emptyset/B_z)$, cm	∞	2333	1750	1400	1166	1000
$r_B = B_z/B_\emptyset$	-	7.5e-3	1e-2	1.25e-2	1.5e-2	1.75e-2
$\Delta = 2\pi R(B_z/B_\emptyset)$, cm	0	1.88	2.51	3.14	3.76	4.39
$N = L_v/\Delta$	closed	9.2	7	5.5	4.6	3.9

Table-1: Variation in L_c, r_B, Δ and N with variation in B_z is shown.

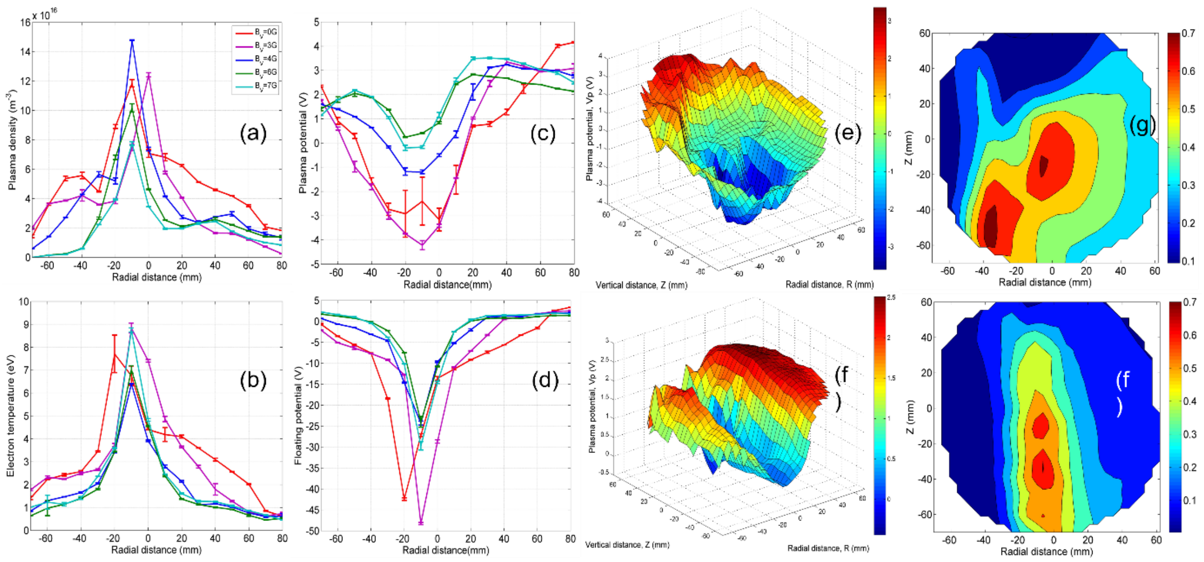

Fig.1. (a-d) 1D profiles of plasma density (n_e), electron temperature (T_e), plasma potential (V_P) and floating potential (V_F) for B_z between 0 G-7 G. (e-f) 2D profile of V_P at 0 G & 6 G. (g-h) 2D profile of average ion saturation current fluctuation measured for B_z=0 G & 6 G.

Observation indicates that with increase in B_z nature of the plasma profiles changes from nearly circular broader one to very narrow vertically elongated profile. Figure (e) & (f) indicates that the potential well changes from a circular potential well to canyon with narrow elongated channel in the center with plateau on both sides. Complete evaluation of the profiles indicated that, plasma parameters have their optimum value at B_z=0.4 mT. Note that 1D potential profiles is not depicting this observation due to the fact that the data is obtained diagonally at an oblique angle which is not passing through the potential minimum. This B_z corresponds to the value at which perpendicular transport nearly balances the parallel transport. In other words, $B_z < 0.4$ mT or N > 7 is dominated by perpendicular transport and $B_z > 0.4$ mT or N < 7 is dominated by parallel transport. In literature these two regimes are characterized with resistive and ideal interchange respectively [7]. Further, as shown in figure 2 (a & b), it is observed that increase in B_z resulted in suppression of both density and potential fluctuation. Analysis of ion saturation current fluctuations indicate that they are mostly dominated by bursty intermittent events. The edge or low-density region is characterized with upward going intermittent events with positive skewness value and center core or high-density plasma region is identified with non-gaussian downward going events with negative skewness. An intermediate region is characterized with gaussian statistics, identified as blob birth zone. The radial variation of higher order moments of PDF is very similar to that of edge region of fusion devices and when skewness plotted against kurtosis, a unique parabolic relation is observed.

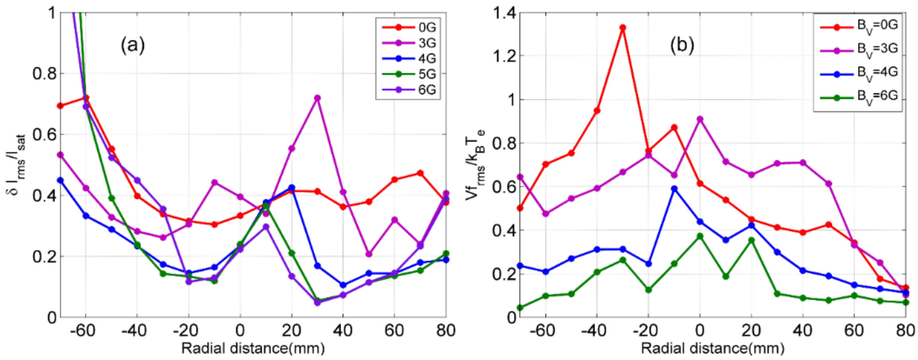

Fig.2. Relative density and potential fluctuations for variation in B_z are shown.

To understand the spatio-temporal evolution of coherent structures 2D conditional averaging analysis is performed. This technique extracts coherent part of the fluctuation from asynchronous measurements taken from different spatial location. It involves simultaneous measurement of time series signals from a fixed reference probe and a scan probe. The later one scans the whole poloidal plane under investigation. A set of events within a time series fluctuation is identified from the fixed probe signal when a threshold condition is met. The threshold condition set to trigger the events in this experiment is 2.5σ, where σ is the standard deviation.

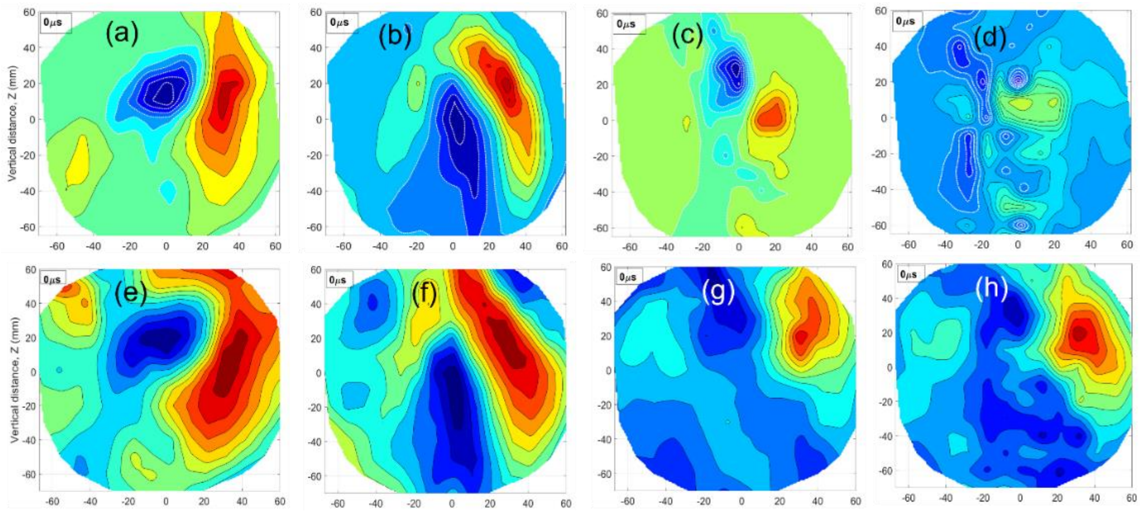

Fig.3. (a-d) Snapshots of the conditionally averaged $\tilde{I}_{sat}$ fluctuations for time delay 0 μs respectively for B_z=0, 3, 5 and 6 mT. The same obtained from two-point cross correlation measurement is shown in figure (e) to (h).

Snapshots of the conditionally averaged $\tilde{I}_{sat}$ fluctuations indicate the existence of large-scale density structure propagating poloidally in the cross section. It shows mostly dipole like positive and negative vortex structure having nearly same amplitude and their propagation is dictated by background plasma flow. Detailed analysis indicates that a blob like structure forms from a positive structure propagating poloidally in the background flow in the high field side. The structure breaks apart in the shear layer due to the differential stretching where the leading part moves with a relatively faster velocity leads to its detachment and formed as blob. This newly formed blob convected to the low field side and ultimately to the limiter by $\boldsymbol{E} \times \boldsymbol{B}$ flow for the sheath disconnected blob. Two-point cross correlation measurement (fig.3(e-h)) concur the observations made from conditional averaging method except the fact that they overestimate the size and lifetime of the structure. The geometry and size of the blob structure depend very much on the vertical field B_z.

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