Suppression of Turbulence in the Large Plasma Device via Rotation

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Abstract

Suppression of turbulence has been observed in the Large Plasma Device in the presence of flow shear. Using an iris-like setup of biasable metal plates called limiters, azimuthal flow near the edge of the device was achieved. The limiters extend from the inner surface of the device inward, 28.5cm from the central axis, and are set from 0 V to 200 V above the anode. Multiple probing methods including the use of a Mach probe, a nine-tip Langmuir probe, and a fast camera make it possible to create radial profiles of the flow, v_θ, and the electron temperature, T_e, among others.

1 Introduction

In a plasma where there is a pressure gradient, ∇p, there is an emergence of turbulence. This turbulence is due to the inherent instabilities of a nonuniform plasma. Another source of instabilities, i.e. another source of free energy for turbulence, of a fluid is flow shear. However, it has been observed that flow shear in either a linear or toroidal plasma stabilizes the ∇p instabilities[1,3,5].

Confinement of plasma is a much-desired phenomenon, especially for ventures toward thermonuclear fusion. Naturally, a society that chooses to seek fusion energy as an option to pursue would desire to control plasma confinement at will. The leading difficulty of confining a plasma comes from the inherent turbulence within the plasma itself. This turbulence causes a mixing of the plasma at different radial positions.

Since flow shear suppresses turbulence, a method to drive flow only for a certain range of radial positions would be highly useful. Since significant overall flow would be limited to only a slice of the plasma, flow shear may be indirectly controlled.

By imposing different boundary conditions for different radial positions, this is indeed easily achievable, whether the plasma is produced in a tokamak or a linear device. In this paper, we consider a linear, magnetized plasma with radially dependent boundary conditions. The driven flow at the edge of the plasma was augmented not only with the use of different boundary conditions (via biasing these boundary conditions against the plasma source) but also by using different magnetic field strengths.

2 Experimental Setup

The device used in this experiment is the Large Plasma Device (hitherto, LaPD). With a cylindrical base, the LaPD is 17m long and produces a plasma that is typically approximately 60cm in diameter. A series of ring magnets is situated along the LaPD, each ring being concentric to a circular cross section of the base cylinder. The LaPD is evacuated then filled with helium gas (on the order of 10^{12} cm^{-3}). A constant and uniform magnetic field, $\mathbf{B}$, is applied throughout the chamber. It points to the left in Fig. 1. The same experiment was run at different values of $|\mathbf{B}|$. For the data and analysis presented here, we have $|\mathbf{B}| = 1000$ gauss.

Within the LaPD and at one edge is a cathode-anode setup. The cathode is a barium oxide coated nickel plate that is heated. The heat and the electric potential between the cathode and the anode (a mesh) provide a necessary condition to create a "beam" of electrons. This beam flows into the helium gas, producing a plasma throughout the inside of the LaPD. It is important to note that the plasma is created locally, so the entire device lights up at (essentially) the same time.

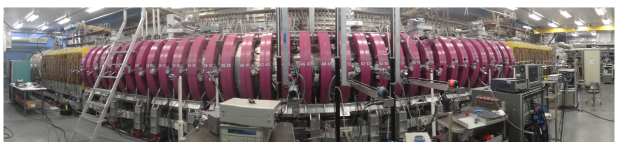

Fig. 1: a panoramic view of the LaPD.

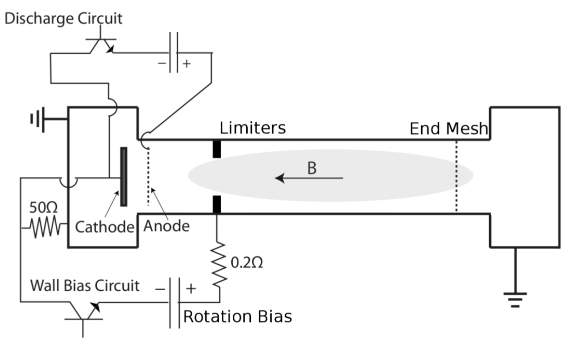

Fig. 2: a schematic representation of the circuitry of the LaPD.

Notice the label "Limiters" in Fig. 2. The limiters are two metal plates that can be biased against (set at a potential relative to) the anode. The limiters extend from the base cylinder of the LaPD to about 28.5cm from the LaPD's central axis. In this experiment, the limiters are set between 0 V to 200 V above the anode mesh. Between these two voltages, a total of 33 different biases were used.

3 Techniques

The experiment consisted of multiple probing methods including the usage of a Mach probe, a nine-tip Langmuir probe, and a fast camera. The author of this paper was responsible for the Mach probe data.

Each probe was attached to a rig with horizontal and vertical drives. The horizontal drive allowed for the radial profiling of the plasma.

There are multiple kinds of Mach probes, namely rotating and Gundestrup. The Mach probe used in this experiment is of the Gundestrup sort, having an octagonal cross section. Of the eight tips on the measurement end of the probe, only six are actually used to collect ions. Each tip is just under 0.5cm from corner to corner. The orientation of the Mach probe is such that tips 4, 5, and 6 face the cathode-anode set up and tips 1, 2, and 3 face the other end of the LaPD. The remaining two sides, facing either up or down, are unused. The overall orientation of the tips is numerical and increasing counter-clockwise when looking at the end of the probe straight-on. A digitizer connected to the probes then reads out the emf, which is converted to a current–the so-called "I_{sat}"–via Ohm's Law.

A Mach probe indirectly measures the flow of the plasma. Using the current calculated from each tip, it is possible to find the average Mach number of the collected ions. Provided that the electron temperature, T_e, is known, the flow (v_θ) can then be calculated[2]. To obtain a radial profile of T_e, data from the Langmuir probe must be analyzed. Such analysis is still in progress.

4 Data

Since I_{sat} for each tip is a function of time, bias, magnetic field, and position within our dataset, it was possible to obtain various kinds of profiles of the flow, or some proxy for it. Namely, special attention was given to the temporal and radial profiles of each $I_{sat,i}$, where i refers to which tip, thus $i \in \{1, 2, 3, 4, 5, 6\}$.

For two examples of the temporal profiles, $I_{sat,i}$ vs t, refer to Fig. 3.

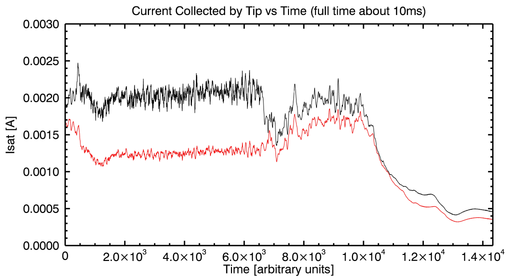

Fig. 3. Temporal profiles of $I_{sat,i}$ for $i = 3$ (black trace) and $i = 6$ (red trace) at high bias far from the core.

In order to determine the azimuthal flow as a function of position, the formula[2]

$$M_\theta = \frac{M_c}{2}\left(\ln\frac{I_{sat,5}}{I_{sat,2}} - \ln\frac{I_{sat,6}}{I_{sat,3}}\right) \qquad (1)$$

may be used, where $M_c \approx 1$ is known as the calibration factor. Tips 4 and 1 were then used in place of 6 and 3, respectively, then the average was taken. Fig. 4 shows the resultant M_θ values plotted against radial position in the plasma at various biases.

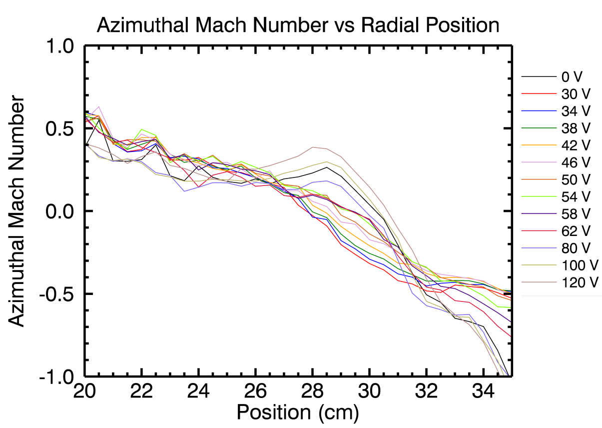

Fig. 4. Radial profiles of M_θ at different biases.

As a way to probe the turbulence itself, the fluctuations of each $I_{sat,i}$ were studied. To do this, the squared modulus of the fast Fourier transform (FFT) of each $I_{sat,i}$ was calculated.

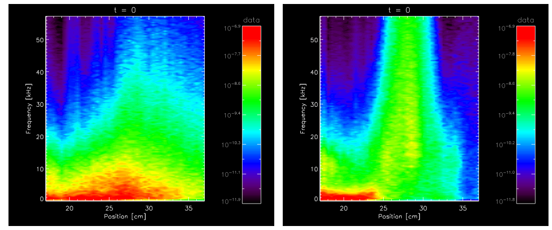

Fig. 5. *Left*: fluctuation plot at no bias. *Right*: fluctuation plot at high bias.

5 Analysis

Consider the black trace in Fig. 3, i.e. the trace with larger I_{sat}, on average. There is a distinct interval in which I_{sat} oscillates about some constant value. The oscillations are the fluctuations to be studied later. This interval corresponds with the period of time that the limiters are (highly) biased against the anode. Before and after this time interval it is evident that each $I_{sat,i}$ is not constant. This is due to the turbulence.

The reason for the discrepancy between tips is simple: one tip not only collects ions electostatically, but more ions collide with one tip due to their initial translational angular momentum far from the tip. In the case of Fig. 3, we have that tip 3 collects more ions than tip 6.

Fig. 4 reveals a general trend for the M_θ vs. r profiles at different biases, where r denotes the position from the central axis. From around 28cm inward, it appears as though the azimuthal flow is nearly constant. Upon comparison with data obtained from the Langmuir probe along with the camera, we see that the core (i.e., positions less than 28cm from the central axis) should have nearly zero azimuthal flow. This reveals that the Mach probe is not a perfect instrument for measuring flow.

Of special notice is the general trend of the profiles at locations beyond 28cm. This reveals that the limiters drive flow in the edge (part of the plasma that is not the core). The decreasing nature of the profile may suggest that the angular velocity of the plasma edge may be nearly uniform, 28cm outward.

In Fig. 5, avg($|fft(I_{sat,i})|^2$) is represented by the color axis. We will call this the power. The averaging is taken over the tips. For the more violet regions in the plots, the fluctuations are relatively low. On the other end of the spectrum, the reddest regions denote the highest powers. Note that the color scales of each plot differs slightly from the other. The horizontal axis of each graph denotes the radial position (in cm), having the same range as Fig. 4. Since the FFT was used on $I_{sat,i}(t)$, the vertical axis represents the frequency, ν, of the fluctuations (in kHz).

As noted before, the color scale of each plot differs from the other. This is inconsequential, for only the general shape of each shall be compared to the other. In the zero bias case, cuts of the plots for $r =$ constant for each value of r are generally the same: the power starts off high near $\nu = 0$, then it smoothly decreases as ν increases. For the high bias case, this is only true in the core. In the edge, the fluctuations are essentially constant. This may hint at the suppression of turbulence in the edge. More analysis is needed to better determine the truth of this statement.

One thing to note is the apparent peak in frequency in the high bias case of Fig. 5. This peak occurs between 10 and 30 kHz.

6 Closing Remarks

Given the above data, a logical conclusion of how the limiters affect the plasma is that they rotate the edge of the plasma, while not affecting the core–at least as much. That rotation is a function of bias. Indeed this was what was observed in previous works[1,3]. Unlike before, this experiment was conducted for various magnetic field strengths. However, the author has yet to study the magnetic field's effect on the flow profile.

As an aside, in previous works, evidence of a coherent mode appeared in the I_{sat} fluctuations. In the data presented here, no coherent mode was evident. However, subtle hints at a possible coherent mode did appear. A comparison of the Mach probe data with the other data may shed light on the nature of these coherent modes, if at all present in other magnetic fields.

Moreover, the entire experiment has been re-run, allowing for new data to be analyzed. This may provide the opportunity to determine how the Mach probe is flawed, as well as where the probe performs well.

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