36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, D-2.001 (2009)

Two-Dimensional Turbulence Analysis Using High-Speed Visible Imaging in SLPM Plasmas

M. Passas, O. F. Castellanos, J. M. Sentíes, E. Anabitarte.

Departamento de Física Aplicada. Universidad de Cantabria, 39005 Santander, Spain

1. Introduction

High-speed imaging techniques[1][2] have been used for years as a relevant way to study some plasma features combined with traditional diagnostic techniques. In this context, two dimensional SLPM plasma features using high-speed imaging techniques have been investigated. These images have been recorded from the SLPM main borosilicate window perpendicularly located to the main axis of the plasma cylinder [3]. The aim of this study is to detect localized coherent structures (blobs in the literature) in the plasma images and extract their geometrical characteristics (position, scale, orientation angle and aspect ratio) using an image analysis method based on two-dimensional continuous wavelet transformation (2D-CWT) [4]. Preliminary studies of bidimensional coherence between SLPM plasma images and the ion saturation current of a Langmuir probe will be presented.

2. Experimental Setup

Plasma is performed in a cylindrical stainless steel vessel with an internal diameter of 0.15m and a length of 0.92m. Magnetized plasma is produced by launching longitudinally electromagnetic waves (LMG) with a frequency of 2.45 GHz into the circular waveguide through a turnstile junction. Incident power (*P*LMG) ranges between 0.6 kW and 6 kW. Stationary longitudinal magnetic field can vary between 0.05T and 0.15T and it is generated by six water-cooled coils, which are concentric with the stainless steel vessel and the waveguide. The gas working pressure varies between 10^{-3} an 10^{-1} mbar. Langmuir-Mach probes array consists of one set with 4 tips of 2mm long and 0.5mm of diameter which provide ion saturation current fluctuations and floating potential fluctuations and another two probes which are located along the magnetic field and provide the parallel Mach number. This array is integrated in a fast movable remotely controlled system allowing the radial displacement of the probes inside the vacuum chamber. Two more windows (with diameters of 4 and 15cm, respectively) are sealed with a boron-silicon glass through which visual inspection and high speed imaging of plasma visible light emission techniques are possible. Fluctuation measurements were digitalized using seven fast data acquisition channels with a sampling rate of 1MHz, which are connected to the probes and to the linear potentiometer, and 2×10^6 points per channel are saved with an ADCs resolution of 12 bits. A Photron APX RS camera with CMOS sensor technology and a maximum frame rate of 2.5×10^5 fps was used in this experiment combined with a Nikon AF 85mm f/1.8D lens.

3. Experimental Results

Two kind of experiments have been developed: coherent structures characterization and bidimensional coherence between SLPM plasma images and the ion saturation current of a Langmuir probe in magnetized Argon plasmas (B_0= 100 mT, P= 7×10^{-6} bar, P_{inc}= 1.4 kW).

• <u>Coherent structures characterization:</u>

The goal of this experiment is to identify typical geometric characteristics of coherent structures in SLPM plasmas. To do this, image processing techniques have been developed consisting of detecting these kind of structures and finding their length, width and inclination angle, such as their relative position in the main vessel of the SLPM. Photron APX RS has the restriction of reducing the spatial resolution while frame rate increases. Due to this limitation, plasma images have been recorded without intensifier at 5×10^4 fps with a 256 by 144 pixels resolution to capture the blob-like structures and the Langmuir probes whole plane.

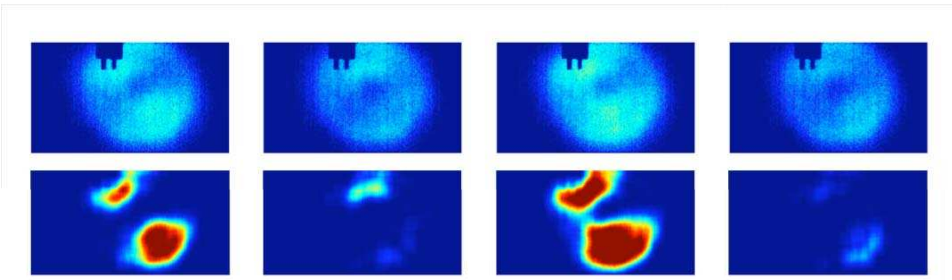

Figure 1: Blob detection in Ar plasma. Shot #2820 100mT, 1,4kW, 7×10^{-7}bar. Raw frames and detected structures.

The method followed consists of detecting and extracting the structure properties of 5×10^4 consecutive frames. First, a thresholding of the frames is done to eliminate weak structures. Next step is to convolve these frames with a 2D Mexican Hat Wavelet to detect the structures remained. Once the structures are detected we isolate each blob to analyse them separately. Then, we identify their relative position by means of the blobs "center of mass". We created a 2D continuous wavelet consisting of a straight line centered in each blob which is used to find the maximum and the minimum length of the blob and to calculate the angle between the main axis of it and the horizontal plane, by rotating itself through the "center of mass” calculated before. Typical results are to find two intermittent main structures in SLPM plasmas separated about 10 mm one from each other, with a rotation angle of approximately 150º, radially opposite from the plasma centre. The upper one appears commonly close to the Langmuir probes, at ≈5 mm from their centre and ≈-20º of inclination from the horizontal plane of the probes. It uses to have an average dimension of ≈5 mm width and ≈10 mm length, with ≈40º of inclination from the horizontal plane. The lower structure average dimension is about 7 mm width and 10 mm length, with approximately 50º of inclination from the horizontal plane. It is commonly located ≈20 mm from the probes centre and approximately -50º of inclination from the horizontal plane of the probes. Four of the images recorded and their detected blobs are shown in figure 1. From the analysis of this features of plasmas we found intermittent structures in Argon plasmas and no rotational movement of blobs. New experiments to induce blob rotation by means of induced electric field will be developed. We also want to compare the effects of spontaneous and biased induced shear layers on these geometrical aspects of blobs in SPLM plasmas with the results obtained in other plasma devices.

• Bidimensional coherence between plasma images and the ion saturation current of a Langmuir probe:

As it was shown in figure 1, there is a blob-like structure very close from the probe tips. We want to know if this structure fluctuates according with the probe ion saturation current. In this context we have analysed the bidimensional coherence between 2^{16} plasma images (recorded with Photron APX RS camera at 250 kfps with a 14 by 71 pixels resolution centered in the probe tips) and 2^{16} samples of the ion saturation current of a Langmuir probe at 250 kHz. We will use these results to compare them with those from similar experiments developed in other plasma devices. Six pictures representing the spatial coherence mentioned

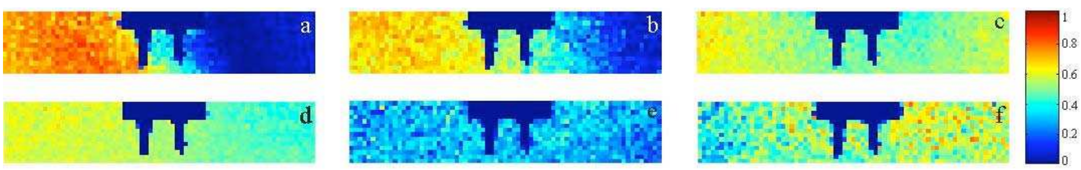

Figure 2: Shot #2826 Ar plasma, 100mT, 1,4kW, 7×10^{-7}bar.

Bidimensional coherence between Is and fluctuations in images at different frequencies.

a) 18311 Hz b) 23682 Hz c) 31818 Hz d) 61270 Hz e) 86100 Hz f) 111330 Hz before, calculated at six different frequencies, are shown in figure 2. The coherence shows a maximum at 18311 Hz, supporting the interpretation of fluctuations on light intensity as density fluctuations as its in shown in [5]. Light intensity fluctuations PDFs show gaussian behaviour around the probes, as seen in figure 3. Typical mean value of light intensity fluctuations skewness is around 0.3 and kurtosis commonly shows an average value between 3 and 4.

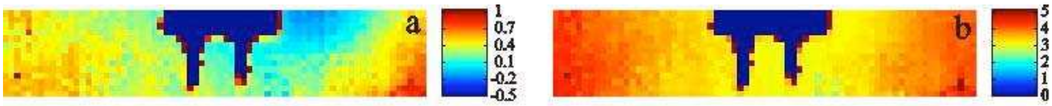

Figure 3: Shot #2826 100mT, 1,4kW, 7´10-7bar. Spatial skewness (a) and kurtosis (b) of light intensity fluctuations.

4. Summary and Conclusions

Combined measurements of high-speed camera images and reciprocating Langmuir probes have been used to characterize coherent structures in SLPM plasmas. It is common to find two intermittent structures in Argon plasmas separated approximately 10 mm one from each other, with a rotation angle of about 150º, radially opposite from the plasma centre. Neither poloidal nor radial motion have been appreciated. Further studies are in progress to induce that kind of motion during biasing experiments in Helium, Neon and Argon plasmas. In the other hand, coherence between light emissions near to the probe tips and the ion saturation current of the Langmuir probes is almost maximum at different frequencies, which suggests that light intensity fluctuations are related to electron density fluctuations at those frequencies. Statistical analysis of the temporary images will be done due to the huge volume of frames recorded at 250 kfps (up to 1×10^6 per shot). Preliminary results show a gaussian behaviour of the light intensity fluctuations around the probes radial position.

Acknowledgments

This work was supported by Dirección General de Investigación of Spain under Project Nº ENE-2006-15244-C03-03

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