ON THE DYNAMICAL BEHAVIOR OF A HIGH-FREQUENCY PLASMOID

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1. Introduction

Recent studies showed that well located complex space charge configurations (CSCC), generated in a plasma submitted to a sufficient strong external constraint, exhibit a proper dynamics [1]. This behavior can turn into a chaotic one if this constraint reaches a critical value. Controlling the dynamics of such complex systems, especially their chaotic behavior, is of a great interest in the last decade [2].

A CSCC appears as a plasmoid [3] in a high-frequency (HF) plasma. Its self-consistence is ensured by a double layer (DL) self-assembled at its border. Under certain experimental conditions, the plasmoid reveals a proper dynamics, evidenced by periodic variations of the light emission and by a modulation of the HF field. In this paper we report experimental observations on the dynamics of the plasmoid depending on the external constraints applied to the HF discharge. Our research also proves that its dynamics can be controlled using an electron beam periodically injected in the region where the plasmoid is formed.

2. Experimental results and discussion

The experimental setup is schematically presented in Figure 1. It consists in a glass tube, 30 cm long and 5 cm inner diameter, filled with Argon a pressure of 1 Pa. The plasma is excited using two metallic parallel bars forming a Lecher line, coupled to a Hartley generator, whose frequency \( \nu \) is 100 MHz. The gas pressure assures that the discharge is controlled by secondary electrons emitted by the glass wall. The energy transferred from the generator to the discharge can be controlled varying the control parameter of the system, namely the voltage \( U_S \) applied to the screen grid. As a measure of the energy absorbed by the discharge one uses the control grid current \( I_G \). The value of this system parameter is falling when the amount of the absorbed energy is rising. The two parameters are registered using a XY plotter, obtaining the \( U_S - I_G \) characteristic (Figure 2).

The dynamics of the plasmoid is investigated using a photo multiplier (PM). The current \( I_{PM} \) generated by the PM is amplified and analyzed using the first entry of a digital storage oscilloscope (DSO). A thermo-emissive
cathode (TEC), consisting of a heated grounded disk covered by barium carbonate, 5 mm in diameter, is placed at one end of the tube. The electrons emitted by the TEC are accelerated using a metallic grid, with a transparency of 60%. The grid is biased at a step voltage $U_{SG}$ (20V in amplitude) using a signal generator. The signal is recorded using the second entry of the DSO.

The plasmoid is obtained by setting $U_S$ at a value for which an usual HF discharge appears in the glass tube (point a in Figure 2). Decreasing $U_S$ a well-localized CSCC suddenly appears inside the tube having the appearance of a luminous ellipsoidal body, namely the plasmoid. Its spontaneous self-assemblage is accompanied by a sudden fall of $I_G$ (point b in Figure 2) indicating a strong energy absorption and therefore a passage to a resonant state [3]. Simultaneously, both $I_G$ and $I_{PM}$ evidence periodic variations with a frequency $f_m$ of about 25 kHz. A further decrease of $U_S$ determines an increasing of $f_m$ up to 45 kHz. At a certain critical value of $U_S$ (point d in Figure 2), $I_G$ increases indicating that less energy is absorbed by the plasmoid. Its border becomes more sharply, his luminosity increases and $I_{PM}$ becomes constant, indicating that the plasmoid is in a stable state. If $U_S$ is further decreased, no significant modification can be observed in the behavior of the plasmoid. For a critical value of $U_S$ (point f in Figure 2) the plasmoid disappears.

If the critical point f is not reached $U_S$ can be increased without disabling the plasmoid. After a decrease of $I_G$ (branch g-h) the plasmoid becomes diffuse and $I_{PM}$ periodically varies again. The temporal series observed in the variation of $I_{PM}$ are analyzed using their power spectra. One can remark that, for lower values of $U_S$ (13.79V), the power spectrum exhibits one frequency $f_1$ with its harmonics (Figure 3a). When $U_S$ reaches 14.33 V, a second incommensurate frequency $f_2$ with its harmonics emerges (Figure 3b). Since the control parameter is still low ($U_S$=14.82V), the two frequencies are present (Figure 3c). If $U_S$ is raised (15.08V), the magnitude of $f_2$ becomes insignificant (Figure 4d).

Figure 2: $U_S$-$I_G$ characteristic of the plasmoid
This behavior is determined, as already shown [3], by the dynamics of DLs successively generated at the border of the plasmoid. The scenario of this dynamics involves elementary processes, namely excitation and ionization of neutrals by electron collisions. These processes are taking place in two adjacent regions, determining the accumulation of opposite space charges and the genesis of a DL that borders the plasmoid. At a critical value of the absorbed energy, the region where electrons experience excitation is shifted away from the border of the plasmoid and the DL is moving toward the wall, where it disrupts. This process is triggered by electrons released by the previous DL disruption so that it becomes periodic. The frequency $f_1$ emerging in the power spectrum of $I_{PM}$ can be determined by the shelling off process of the DL. The second frequency $f_2$ can be correlated, in our opinion, with the formation and the dynamics of a second DL at the border of the plasmoid. Experiencing their own dynamics, the two DLs meantime created determine the co-existence of two frequencies in the power spectrum until the strong value of the external constraint determines a coupling between the two DLs and the disappearance of $f_2$ from the spectrum. A similar behavior was reported in the case of a DC plasma [1].

In the following we propose an experiment demonstrating that this mechanism can be controlled using electrons from an external source. After the formation of the plasmoid, $U_S$ is decreased to about 13 V in order to obtain an unstable state when the light emission (evidenced by $I_{PM}$) periodically varies with a frequency $\nu_P$ of 27.3 kHz. In the following, all the parameters concerning the discharge are maintained constant. A positive step voltage $U_{SG}$ (20 V in amplitude) is applied to the grid (Figure 4 c). In this way, a pulsed electron beam is injected toward the plasmoid. The frequency $\nu_{SG}$ of the bias voltage is chosen to be close to the proper frequency $\nu_P$ of the unstable plasmoid. The DSO evidences that the two signals become coupled.
If $v_{SG}$ is modified, the DSO evidences that the modulation frequency $v_P$ of the plasmoid is entrained, following the first one. The first column in Figure 4 shows that the signals generated by $U_{SG}$ and $I_{PM}$ are strongly coupled, even if $v_{SG}$ is decreased (Figure 4 a,b) or increased (Figure 4 d,e). The same is evidenced by the power spectrum of the two signals (second column in Figure 4), showing that the two frequencies and their harmonics have identical values. The registered data show that the entrainment band is about 15% of $v_P$ (between 23.4kHz and 33.2kHz). If $v_{SG}$ passes these limits, $v_P$ suddenly regains its initial value, namely 27.3kHz.

This experiment evidences that a modulated electron beam can determine variations of the proper frequency of the plasmoid in a certain domain, confirming that electrons are at the origin of the triggering mechanism of the DLs shelling off process. If the electrons from the beam are arriving before the DL disruption ($v_{SG} > v_P$), they are injected in the region where a new DL is forming, determining its shelling off process with the frequency of the beam injection. If $v_{SG} < v_P$, the electrons from the beam are modifying the electric field in the region where the DL just starts its disruption and they are delaying the resulting electrons to gain the new forming DL. In this way, the frequency of the DL dynamics is controlled on a limited band. If the limits of the entrainment band are exceeded, the plasmoid retrieves its proper dynamics. Modifying $v_{SG}$ in order to return in this band one can remark that the plasmoid can be entrained only if the frequency of the beam is decreased under the upper limit or is increased over the lower limit of the entrainment band.

3. Conclusions

In this paper we report experimental observations on the dynamics of a HF plasmoid. Varying the amount of the energy injected in the HF discharge one can evidence the transition of the plasmoid in an unstable state, characterized by temporal variations of the HF field and also of the emitted light. Our experiment also demonstrates that the proper dynamics of a plasmoid can be controlled using a modulated electron beam. Taking into account the similarities between the plasmoid and CSCCs formed in DC plasma devices [4], we consider that this method could be applied to control the dynamics of such structures, even in the case when their behavior becomes chaotic.

References