

Dynamics of the plasma of a twin discharge system induced by external perturbations

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In this work we present new results on the dynamics of charge structures generated in the inter-anode space of a twin electric discharge system both for free running and for sinusoidal forcing. We study the change of plasma dynamics as function of the amplitude of the ac forcing for two dc biasing values. In a certain range of the control parameter, proportional to the amplitude of the sinusoidal perturbation, the dynamics can be dramatically changed. The results of the computational model proposed in previous works for the system are in reasonable agreement with the experiment.

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Key words: discharge plasma, van der Pol, chaos

1 Introduction

On a particular case of harmonic perturbation (with given amplitude and frequency), the possibility of modelling of the dynamics of perturbed charge structures of double layer (DL) type – as dynamics of coupled Van der Pol oscillators was demonstrated [1]. Based on the same idea now, results of a more in depth study on a perturbed discharge plasma DL are presented. We study the change of plasma DL dynamics as function of the dc biasing and the amplitude and frequency of the ac forcing. In a certain range of the control parameter proportional to the amplitude of the sinusoidal perturbation, the DL-dynamics is sensitive to the frequency of the perturbation and the value of the dc biasing. This means that the transition of DL dynamics from periodic to chaotic and vice-versa can be induced in another way than by the trivial method of variation of the dc biasing. of course, this gives the possibility of control of the chaotic behavior of the DL through the amplitude or the frequency of a harmonic perturbation [2]. The experimental results are in good agreement with the predictions of the model.

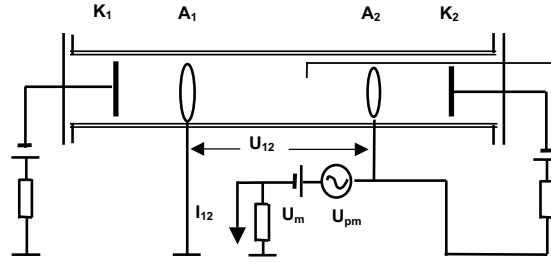


Fig. 1. Experimental set-up: K_1 , K_2 – plane cathodes, A_1 , A_2 – anodes; U_m – biasing supply, U_{pm} – perturbing voltage supply with amplitude U_p .

2 Experimental arrangement and results

The experiments were carried out on a device generating two adjacent glow discharge plasmas in the same tube (Fig.1). The DL structure is formed in the A_1A_2 contact region between the two negative glow plasmas (of the two independent K_1A_1 and K_2A_2 short glow discharges) which are biased one versus the other by an external dc power supply U_m and a sinusoidal perturbation U_{pm} [3, 4, 5]. Time-resolved measurement procedures were used to study the dynamics of such discharge DL. The I_{12} current flowing through DL-forming region is taken as global observing parameter for evaluating of the DL nonlinear dynamics. For this, data acquisition techniques and nonlinear methods of analysis are used.

The temporal pattern of DL-evolution depends on the value of the dc biasing voltage U_m , the sinusoidal perturbation and other experimental parameters (gas pressure, supply currents, etc). In this study, we consider the dependence of the DL-dynamics on the characteristics of the perturbing voltage, for a given state (fixed value of U_m and of the discharge parameters).

Fig. 2a and 2b show spectrograms of I_{12} versus the amplitude of the sinusoidal perturbation. The grey scale shows the amplitude of I_{12} oscillation (white, the lowest level (–90 dB amplitude) and black, the highest level (0 dB amplitude)). Fig. 2a presents the situation where the perturbation with $f_1 = 12$ kHz is applied to the system in a periodic state (for $U_m = 27$ V). With increasing the amplitude of the perturbation, the system goes through various types of dynamics, both periodic and chaotic. For the highest amplitude used ($U_p = 8$ V), the system is periodic again. Similar behavior is observed also for lower frequencies of the perturbation.

Fig. 2b presents the situation with the perturbation applied to the system in a chaotic state (for $U_m = 42$ V). The main effect observed is the generation of a periodic window for relatively low values of the amplitude of the perturbation; at higher amplitudes the system goes back again to a chaotic state. The perturbation frequency in this case is $f_2 = 2$ kHz. When this is 12 kHz, no periodic windows are observed in the range of amplitudes used in experiments.

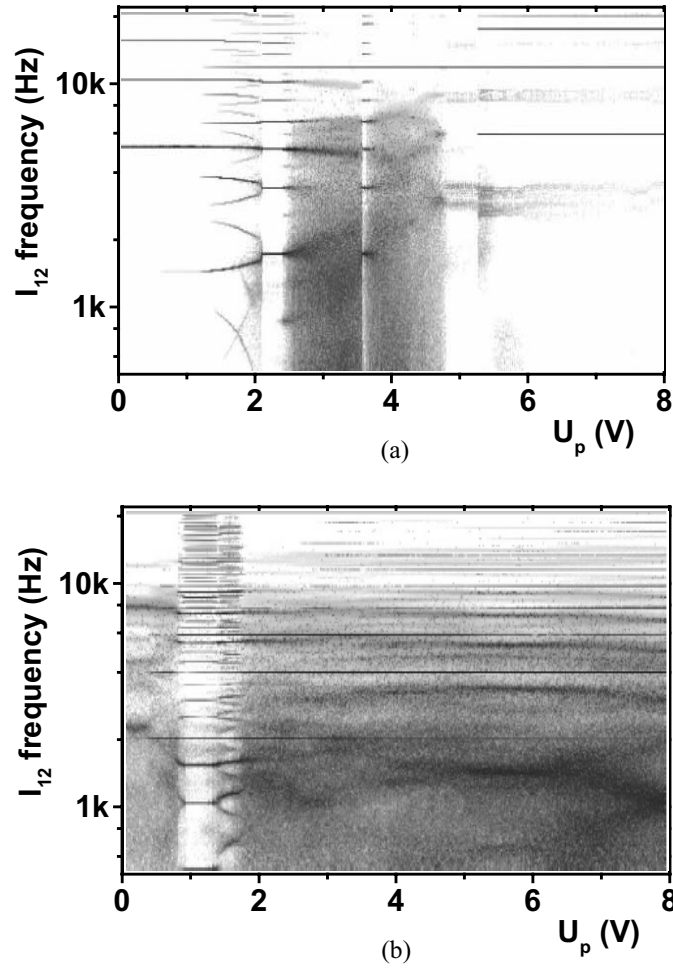


Fig. 2. Experimental spectrograms of I_{12} versus the amplitude of the sinusoidal perturbation: (a) regular initial state, $U_m = 27$ V; (b) chaotic initial state, $U_m = 42$ V.

3 Results of the computational model

The various nonlinear dynamics observed in the behavior of the twin electrical discharge plasma are satisfactorily reproduced by the following model system of equations [1, 6, 7]:

$$\dot{x}_1 = x_2 + m x_4, \quad (1)$$

$$\dot{x}_2 = -c(x_1^2 - 1)x_2 - x_1 + e \cos x_5 + m x_4 + (m - n)x_3 + q m, \quad (2)$$

$$\dot{x}_3 = x_4 - m x_2, \quad (3)$$

$$\dot{x}_4 = -d(x_3^2 - 1)x_4 - x_3 + e \cos x_5 - m x_2 - (m - n)x_1, \quad (4)$$

$$\dot{x}_5 = g. \quad (5)$$

The model consists in a modified version of a system of two coupled van der Pol oscillators corresponding to the two discharges coupled by a dc biasing on which a sinusoidal perturbation is superimposed. The variables have the following meaning: x_1, x_3 – represent currents, x_2, x_4 – stand for voltages and x_5 is the phase of the sinusoidal perturbation with g – the angular frequency. The dc biasing is modelled by the parameter m . In this study, the role of control parameter is played by the amplitude of the perturbation, e (which models U_p). We consider the effect of these perturbations on the dynamics of the system with non-linearity coefficients $c = 1; d = 0.8$. The constants q and n stand for the slight asymmetry between the two discharges. The values used in the present simulation are $n = 0.01$ and $q = 0.05$. The values of the parameter m which models the dc biasing for the two situation in Fig. 2a and 2b are: $m = 1.85$ and $m = 2.56$, respectively.

The graphs in Fig. 3 represent bifurcation diagrams for the system using the amplitude of the perturbation e as control parameter [8]. The upper graph in this figure shows the situation when the perturbation is applied to the system in a periodic state. With increasing e , the system becomes chaotic, then a tinny periodic windows is observed, the system is again chaotic and for the highest values considered ($e = 2$) the system is in a periodic state again. The succession of the zones with different dynamics is similar to the experimental situation shown in Fig. 2a.

The lower graph shows the situation when the perturbation is applied to the system in a chaotic state. The main effect is the generation of a periodic window for low values of the perturbation, similarly to the experimental situation shown in Fig. 2b. Fig. 4a and 4b show spectra corresponding to the behavior presented in Fig. 3a and 3b, respectively. The upper spectrum in Fig. 4a corresponds to the periodic state in which the system existed prior to the perturbation, while the lower spectrum describes the periodic state induced by the perturbation for an amplitude close to the highest value ($e = 1.9$). The arrow marks the frequency of the sinusoidal perturbation. The two spectra are similar and in agreement with the experimental results, the frequencies are slightly displaced to higher values.

The upper spectrum in Fig. 4b corresponds to the left extreme of the bifurcation diagram in Fig. 3b where the system, prior to perturbation exists in a chaotic state. The lower spectrum corresponds to the periodic window in the neighborhood of $e = 0.4$. The spectrum consists in many frequencies and a small noisy component. It is similar to the experimental spectrum in the periodic window around $U_p = 1$ V in Fig. 2b. The arrow marks the frequency of the perturbation.

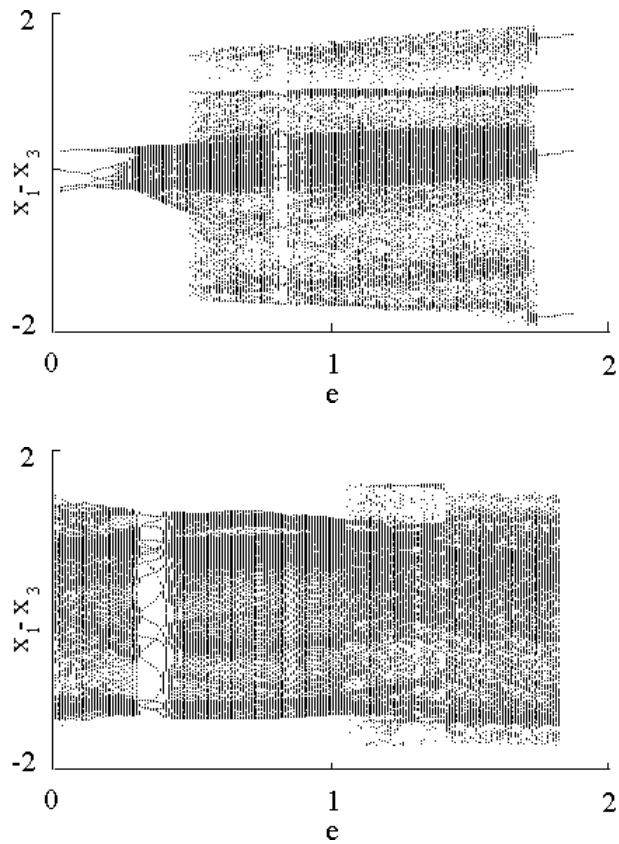


Fig. 3. Bifurcation diagrams for the system using the amplitude of the perturbation e as control parameter: upper $m = 1.85$; lower $m = 2.56$.

4 Conclusions

This work shows that the harmonic perturbation of a twin discharge can considerably change the dynamics of the system. When applied to the system in a periodic state, it can either induce a transition to another ordered state or to a chaotic state, depending on the parameters of the perturbation. When applied to the system in a chaotic state, it can induce windows of periodic behavior or not change the chaotic behavior. The numerical results of the model are in reasonable agreement with the experiment.

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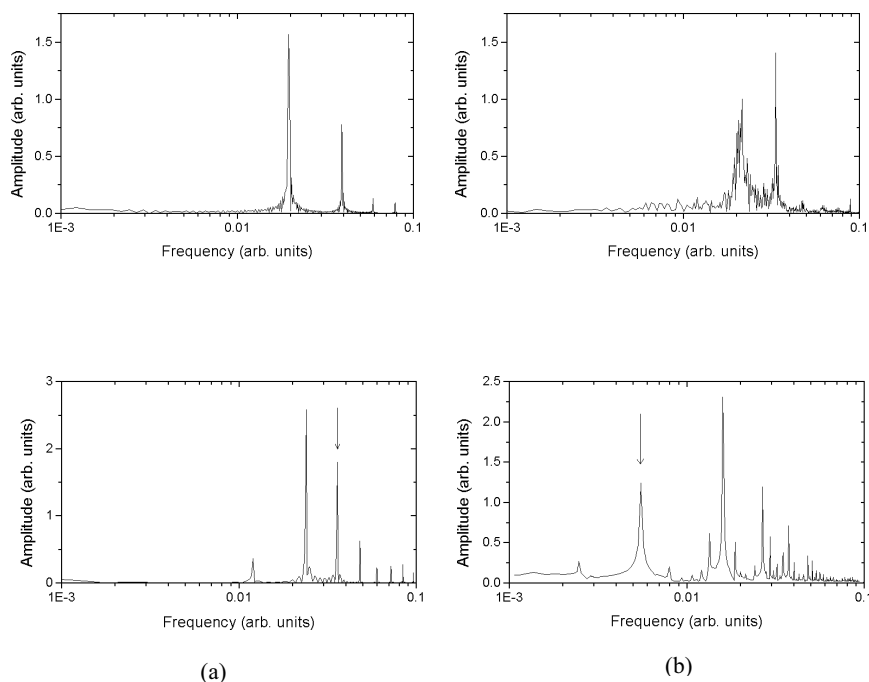


Fig. 4. Spectra corresponding to the values of m used in Fig. 3:
 (a) – initially periodic state ($m = 1.85$): upper $e = 0$; lower – $e = 1.9$;
 (b) – initially chaotic state ($m = 2.56$): upper $e = 0$; lower – $e = 0.4$.

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