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PHASE TRANSITIONS AND CATASTROPHES IN ACOUSTOPLASMA

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ABSTRACT: Plasma is a self-consistent medium, and consequently variation of one of the plasma parameters necessarily leads to others changes. So, smooth changing of one parameter may cause abrupt changes in other parameters. We have shown that sudden jumps of plasma parameters can be described by Catastrophe theory.

In order to describe sudden jumps and phase transitions in acoustoplasma, we developed methods to apply catastrophe theory. It is shown that volt-ampere characteristic of acoustoplasma discharge in CO_2 - laser can be described by means of swallowtail catastrophe, and in an argon-cusp catastrophe.

KEYWORDS: acoustoplasma, swallowtail catastrophe, cusp catastrophe

Catastrophe theory studies jumps in the system by smooth changes in external conditions. Elementary catastrophes formatted in a system as follows. With smooth change of the external control parameters the system rapidly tends to minimize its potential. Thus appear and disappear the local minimums and maximums of the potential. Elementary catastrophe depends on the local minimums disappearance. Only the local maximums are highlighted, where the equilibrium is unstable (it is a critical point) [1]. In catastrophe theory the function can be divided into two parts at the degenerate critical point. One part depends on the variables, which we call control parameters. Another part (calling degenerate) depends on other variables. This reduces the number of variables in concerned problem. Tom showed, that when the number of the control parameters less or equal (≤) to 4, almost any physically realizable function can be reduced to a one of the seven polynomials by local changes of variables. These 7 polinomials define the Tom's seven elementary catastrophes [1].

Geometric images corresponding to the "Fold" and "Assembly" catastrophes can be represented in the real three-dimensional space. But the other catastrophes of higher dimensions can be represented only by three-dimensional cross-sections for the remaining fixed parameters. The catastrophe theory merges all the kind of catastrophes in a one system with control parameters. It is allow to make qualitative predictions about the system behavior, without considering interactions details, in a case when we know only the number of the control parameters [1]. According to R. Gilmore [2], the subject of the catastrophe theory is to study the dependence of the qualitative nature of the solutions on parameters that are presented in the given equations. Elementary catastrophe theory is a science about how the equilibrium of potential function changes by the change of the control parameters.

Acoustoplasma medium contains many parameters and its description by simple mathematical equations (even by a system of differential equations) hindered. Therefore, it is appropriate to use the theory of catastrophes for the qualitative prediction of the acoustoplasma medium behavior. In this article we consider only the "Cusp catastrophe" (CC) and "Swallowtail catastrophe" (SC).

Experiment scheme and setup are similar to those described in [3] (Figure 1). Hysteresis phenomena and nonlinearity have been explored by using current-voltage characteristics of the normal glow discharge (supplying with modulated current). As indicated in [3], acoustoplasma mode is realized in this regime of discharge current.

In Figure 1 (for plasma of CO_2:N_2:He=1:1:8 laser) there are shown the dependences of the normalized voltage across the discharge tube ($<U_{tub}>/U_o$) on the value of discharge current’s constant component $<I_{tub}>$ and the modulation frequency Ω. The value of the discharge current’s variable component is I(~)=8mA and the gas pressure in the tube P_0 = 25torr.

Acoustolasma medium is formed by the variable component of the discharge current in a discharge tube. Then, the variable component of the discharge current is switched off and now there is only a constant component of the current. But acoustoplasma regime still stays, i.e. it has not had time to relax into a state of unperturbed plasma. Here $<U_{tub}>$ is the steady voltage on the discharge tube averaged over a time much larger than the period of modulation, such that all the transition process, except the process related to the acoustoplasma medium creation, had time to relax. U_o is the voltage on the discharge tube corresponding to the value of discharge current’s constant component (without modulation). “Quasi-static” volt-ampere characteristic has been measured for this case.

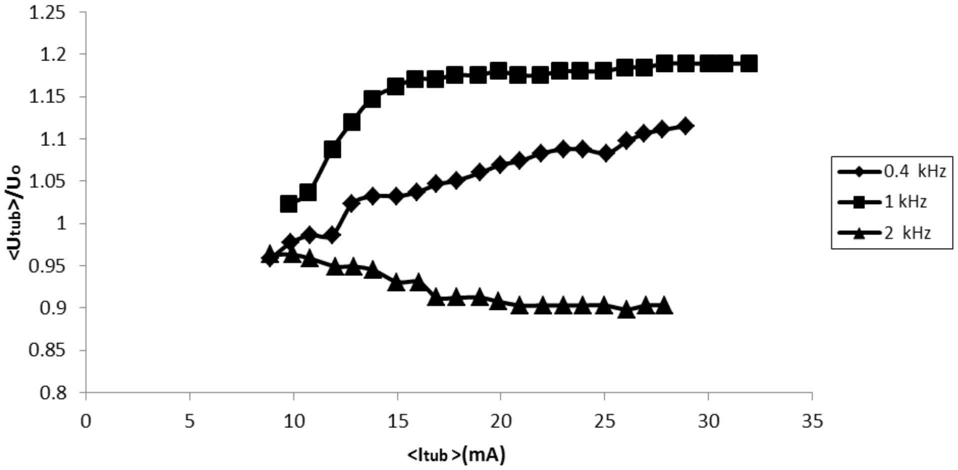

Figure 1: Dependences of the normalized average voltage on the discharge tube on the constant value of discharge current and frequency of modulation; the amplitude of the variable component of discharge current is 8 mA

The experimental curves have been approximated by polynomials corresponding to the first three types of catastrophe. The measurement error of the experiment is less or equal to the size of dots in graphics.

From Figure 1 it is difficult to say if there are sudden jumps or catastrophe in the discharge plasma. Below we show why we believe to the jumps and fact, that the family of curves from the Figure1 can be described by the equations of catastrophes.

"Quasi-static volt-ampere characteristic" clearly has a jump for an argon acoustoplasma (Figure2).

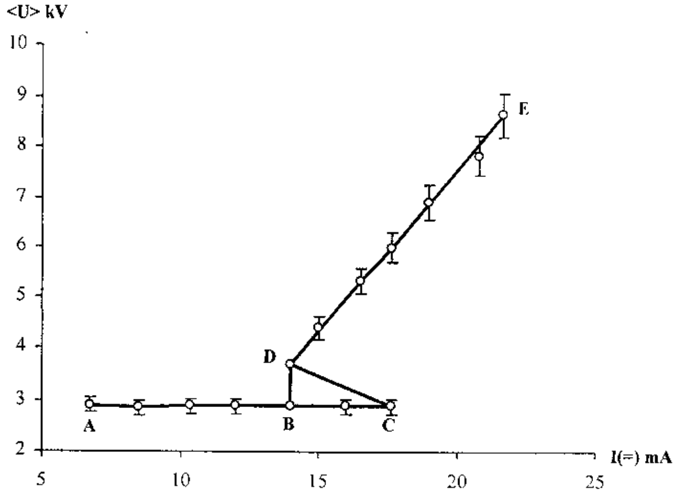

Figure 2: "Quasi-static volt-ampere characteristic" in Ar; gas pressure P_0=350torr, current's alternate component I(~)=1,6mA, modulation frequency f=0,4kHz, I(=) is the steady constant current [4]

Figure 2 shows, that with the increase of the discharge current's constant component (part AC) volt-ampere characteristic's behavior is the same as on constant current. At the point C, for a certain value of <I>, volt-ampere characteristic abruptly changes (part CD). With the further increasing of <I> volt-ampere characteristic again becomes linear (region DE), but with another slope (<U> increases). With the decrease of <I> volt-ampere characteristic repeats the previous movement to the point of jump (region ED). Then <U> abruptly falls to the previous value (region DB). The values of <I> at the points of jumps do not coincide in decreasing and increasing, i.e. a hysteresis is observed.

In addition to the "quasi-static" case, dynamic case is possible when the behavior of the volt-ampere characteristic is considered in a one period of modulating frequency.

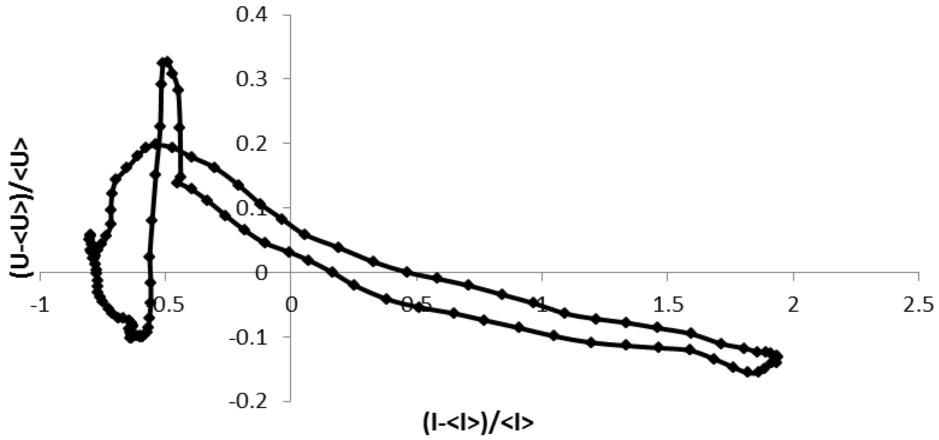

Figure 3: Dynamic volt-ampere characteristic of the discharge current's variable component of the CO_2 acoustoplasma laser

In Figure 3 abscissa represents the discharge current's normalized current values (I-<I>)/<I>. Ordinate is the current normalized values of the voltage at the ends of the discharge tube (U-<U>)/<U>. Here I and U are the values of current and voltage for a period of modulation. <I> and <U> are the values averaged over a period of modulation. Figure 3 shows, that the dynamic volt-ampere characteristic has a jump.

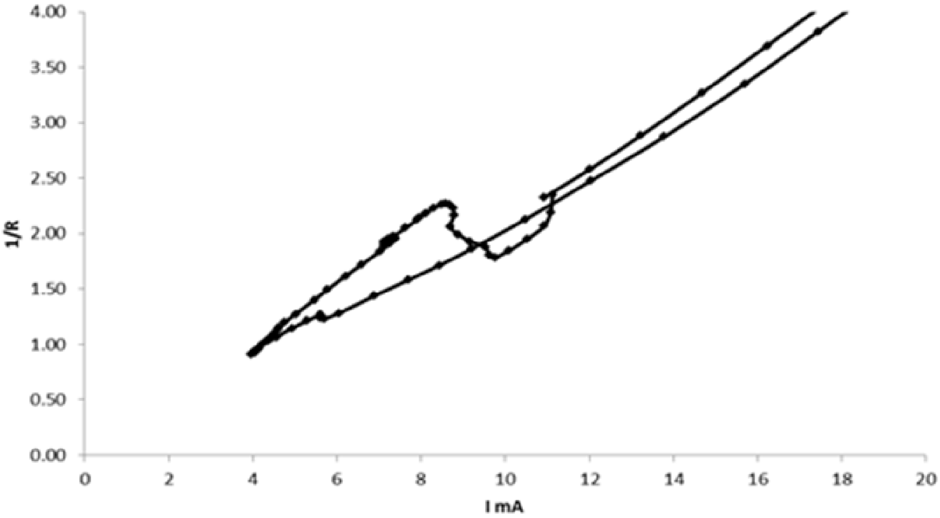

Figure 4: The jump of the CO_2 laser conductivity

Using of the catastrophe theory for describing jumps in plasma was suggested previously [1,2,5,6], but that description had only general qualitative nature.

To describe catastrophes we used approximations of the experimental curves by polynomials. Then according to the catastrophe theory we investigated these approximating polynomials for a presence of critical points and behavior of control parameters. For example, voltage U is a potential function, current I and frequency of modulation Ω controlling parameters. In this case for each Ω we look for an approximation of U by the follow:

$$U = aI^{n} + bI^{n-2} + cI^{n-3} + \ldots + kI + F \qquad (1)$$

Where U and I are the current values measured in time, (a, b, c, …, F) the coefficients obtained through the fitting of experimental curves by polynomials (Figure 1-3). Investigation of the "quasi-static volt-ampere characteristic" approximation by polynomials (through the criterion of "chi-square") shows, that it is described by the “cusp catastrophe” for an argon acoustoplasma, and by the "swallowtail catastrophe" for an acoustoplasma of CO_2 laser. Dynamic volt-ampere characteristic in the plasma of CO_2 laser (Figure3) is best approximated by "swallowtail catastrophe". As for the acoustoplasma of CO_2 laser the "quasi-static volt-ampere characteristic" (Figure 1) is described by “swallowtail” catastrophe, then we can argue, that there are jumps in acoustoplasma.

Following [1,2,4,7], we represent jumps of the plasma parameters as a phase transitions. Research of the conductivity of argon acoustoplasma medium (Figure2) shows, that up to the jump region of the volt-ampere characteristic, with increasing of discharge current, acoustoplasma behaves as a normal unperturbed plasma. At the jump point of volt-ampere characteristic the conductivity jump also occurs. Afterwards, the jump behavior of the acoustoplasma conductivity is similar to the behavior of conductivity of the condensed medium, which can be interpreted as a thermodynamic phase transition from gas state to condensed medium. The conductivity jump of the plasma of CO_2 laser (Figure3) is shown in Figure 4. This jump is not a phase transition from gas to condensed state, because after the jump the conductivity continues to increase with the increase of discharge current. Such phase transitions are discussed in [8].

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