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GROWTH OF RAILEIGH-TAYLOR TYPE INSTABILITY ON THE SURFACE OF DISCHARGE CHANNEL IN LIQUID

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The investigations of growth of corrugations are conducted which arise on an interface between both the plasma channels of electrical pulse discharges and limiting it liquid. The approximate hydrodynamical model of growth of that perturbations constructed and is exhibited, that the corrugations result from Rayleigh-Taylor type instability. The possible mechanisms of saturation of instability surveyed.

The electrical pulse discharges in liquids are studied intensively in connection with its various technological applications. In that discharges a high-density non-ideal plasma column contacts with limiting it condensed medium. The processes on the contact interface are essentially for the properties of the discharge as a whole. The investigation of the growth of irregularities on the interface between a plasma channel of discharge and a water medium is a subject of the given paper.

The most important influence on plasma of electrical pulse discharges in liquid (EPD) have the processes in a zone of its contact with condensed medium. In existing theoretical models of EPD a stream of energy on a wall of the channel and backflow of the evaporated substance were considered homogeneous [1-4]. But on initial phases EPD small-scale irregularities of heat flow distribution were detected on a surface of channels [5-7]. Development of such perturbations was accompanied by space modulation of an irradiation intensity, strain of a surface of channels, drop of conductance of plasma. One from reasons it is established further by comparison of a strain of a surface of plasma channels of EPD with outcomes of simulation on the basis of a solution of the task to development of Rayleigh-Taylor instability (RT-instability). RT-instability in similar conditions was investigated with usage of the numerical methods for a problem of laser thermonuclear synthesis [8-11]. RT-instability in EPD significantly differs from the mentioned case, that does not allow to use outcomes [8-11], but comparatively small degree of compression of a substance around plasma column allows us to consider in an approximation of incompressible fluid the studied problem in an analytical manner.

1. Experimental researches

Experimental investigations of processes under electrical discharges in a water were conducted on the experimental setup where the discharge was created in the chamber filled with a water. To initiate the discharge an explosive wire was used that had allowed us to localize the position of appeared plasma channel. The evolution of plasma channel was recorded through the window by the optical system and the high-speed photochamber.

Observation of development of perturbations of a surface of plasma column is carried out by photography of the bit channel by a fast-track photographic camera. For visualization of a channel surface is applied highlightings by an oblong exterior radiant (flashlight valve**).** The discharges with various rate to input of an energy were researched: R1 is fast, R2 is average, R3 and R4 are sluggish.

The experimental studies have revealed the occurrence of the various kinds of the instabilities of the contact interface, the part from which can be related to the type of the instability of deflagration waves, others to Rayleigh-Taylor ones of an ablative interface.

The perturbations look like ripple on a channel surface, which amplitude reaches 0.2-0.5 mm (5-10 % to radius). Is retrieved, that their development depends on conditions of initiation and rate to input of an energy in EPD. Spectrum of space harmonics of perturbations is bounded above by values of a wave vector k =100-150 ñì $^{-1}$. Filing of the extension of the channel is realized by photography by the camera in the condition of slot-hole development. The computer handling of these data allows to allocate boundary of the channel and to receive time dependence of radius, velocity of the extension and acceleration of a wall of the channel. It is possible to select two different phases of development EPD that are phase of acceleration, when acceleration g_Γ to a surface is directed to the direction towards liquid (g_Γ > 0), that encloses the channel, and phase of deceleration, for that of acceleration is directed towards plasma (g_Γ < 0). The duration of an acceleration phase 2.2-6 μs is less than a first halfperiod of an electrical current (10 μs) in discharge.

2. Linear theory of growth of perturbations

The density of plasma discharge in tens times smaller than density of a limiting liquid and also kinetic energy of macroscopic motion in a contact region concentrated in the main in liquid. It allows at exposition of a strain of a surface of the channel neglect by motion of plasma and to examine only incompressible fluid, having used kinematic parameters of a channel surface (radius, velocity, acceleration) as boundary conditions. In case of small amplitude of perturbations the flow is potential $v = \nabla\varphi$, and in an attendant frame of reference (where boundary of the channel immovable) for perturbation of a potential $\tilde{\varphi}$ by usual methods [12] we obtain the equations:

$$\frac{\partial^2\tilde{\varphi}}{\partial r^2} + \frac{1}{(r+\delta R)}\frac{\partial\tilde{\varphi}}{\partial r} + \frac{1}{(r+\delta R)^2}\frac{\partial^2\tilde{\varphi}}{\partial\theta^2} + \frac{\partial^2\tilde{\varphi}}{\partial z^2} = 0\,, \quad (1)$$

$$\left.\left[\frac{\partial\tilde{\varphi}}{\partial r} + \frac{\partial}{\partial t}\left(\frac{1}{g_\Gamma}\frac{\partial\tilde{\varphi}}{\partial t}\right)\right]\right|_{r=R_\Gamma(t_0)} = 0 \,. \quad (2)$$

Here $R_\Gamma(t)$ is the radius of nonperturbed boundary of the channel, $\delta R(t) = R_\Gamma(t) - R_\Gamma(t_0)$, $g_\Gamma(t) = \ddot{R}_\Gamma(t)$ is fictituous gravitational field, t_0 is an arbitrary fixed instant. For a solution eqs. (1),(2) we search by the way $\tilde{\varphi} = a(t)\sin(m\theta+\alpha)\sin(kz+\beta)\,\Phi(r)$ (m is an azimuthal number, k is a longitudinal wave number). Then for amplitude of perturbation of a potential $a(t)$ in small environment of a point t_0 we obtain the equations:

$$\frac{d}{dt}\left(\frac{1}{g_\Gamma}\frac{da}{dt}\right) = \frac{m}{R_\Gamma(t_0)}a \quad , \qquad (k=0)$$

$$\frac{d}{dt}\left(\frac{1}{g_\Gamma}\frac{da}{dt}\right) = \frac{K_{m-1}(kR_\Gamma(t_0)) + K_{m+1}(kR_\Gamma(t_0))}{2K_m(kR_\Gamma(t_0))}ka\,, \quad (3)$$

where $K_m(x)$ is modified Bessel function of second kind. Having expressed $a(t)$ through the amplitude $A(t)$ of deviations of a channel surface from $R_\Gamma(t)$ And having executed a step passage to the limit on distribution of a full time frame we obtain the equations, that of an appropriate real both in attendant and in a laboratory frame of reference because these equations contain invariant variables:

$$\frac{d^2A}{dt^2} = \frac{m}{R_\Gamma}g_\Gamma A \quad , \qquad k=0$$

$$\frac{d^2A}{dt^2} = \frac{K_{m-1}(kR_\Gamma) + K_{m+1}(kR_\Gamma)}{2K_m(kR_\Gamma)}kg_\Gamma A, \quad k>0 \quad (4)$$

The equation (4) describes an evolution of small perturbations of a surface of the channel in a condensed medium. At $g_\Gamma > 0$ it is Rayleigh-Taylor instability with increment that depends from time, at $g_\Gamma < 0$ it is oscillation of a surface such as gravitational waves on deep water.

3. Mechanisms of saturation of instability

Owing to influx of an energy Q from plasma on a channel surface the intensive ablation of fluid takes place, that reduces in appearance of jet force an ablative pressure p_a. At the expense of the greater stream of an energy on apexes of perturbations, which wedge in plasma column region, the intensity of ablation is higher due to that a pressure gradient is appeared, and that constrains development of instability. The pressure variation $\delta p_a = (\dot{R}_\Gamma / C)\,\delta Q$ at development of perturbations is estimated from an energy balance on a surface ²ÐÐ in an attendant frame of reference (C is the heat of formation of plasma). The magnitude δQ is influenced some by the following factors:

A) Modification of width of a transitional layer. In cross-section of the discharge channel plasma almost isothermal and all thermal gradient is necessary on a thin layer in a surface. Therefore δQ it is possible to estimate, as a variation of a stream of heat at a modification of width of this layer l and

$$\delta p_a = -A\frac{I^2}{4\pi^2\sigma R_\Gamma^3 C l_0}V_\Gamma \quad = -A\,B_1(t) \,. \quad (5)$$

I - current, σ - conductance of plasma.

B) Partial screening of a ultra-violet radiation of plasma by side walls of perturbations. For small perturbations the variation of a stream UV-energy on an apex of perturbation gives

$$\delta p_a = -A^2\left(k^2 + \frac{m^2}{R_\Gamma^2}\right)\frac{\bar{\sigma}T^4}{\pi^2 C}V_\Gamma = -A^2\,B_2(t) \quad (6)$$

C) A modification of heat release at the expense of reallocation of a current density In an approximation of 1-st order the azimuth modes ($k=0$) of perturbations do not change allocation of a current, and for longitudinal modes (L_D is characteristic distance of a diffusion of heat)

$$\delta p_a = -A\frac{2I^2L_D}{\pi^2\sigma R_\Gamma^5 C}V_\Gamma = -A\,B_3(t) \,. \quad (7)$$

For reviewing nonlinear aspects of depressing we shall consider case, when at $t=0$ There is only one mode of perturbations of considerable amplitude. In such situation of limitation of its amplitude will begin earlier, than influence from appearance of upper harmonics. The variation of ablative pressure δp_a reduces in appearance in boundary conditions (2) padding terms, equivalent replacement acceleration $g_\Gamma(t)$ by its effective value $g_\Gamma + \delta p_a/\rho$. The same replacement needs to be made and in the equation (4). The saturation of instability happens at amplitudes of perturbations $A_{\lim}$, for which the right member of the modified equation (4) gains of a zero value.

4. Comparison with experiment and conclusions

In the way of a numerical solution of the modified equation (4) is conducted simulations of various modes of perturbations of a surface of the plasma channel for discharges types R1-R4. At simulation used the experimental data, obtained for these discharges, of radiuses and accelerations of a surface of channels from time, coefficients of depressing of instability B_i is calculated till the formulas (5), (6), (7) with usage of the measured values of temperature and electrical parameters of discharges. Fig.1. shows the calculated time dependencies of amplitudes of longitudinal modes of perturbations.

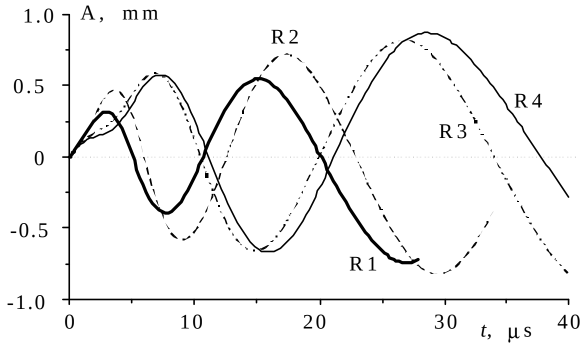

Fig1.The calculated time dependencies of amplitudes of longitudinal modes of perturbations for the discharges R1-R4 .

The obtained results well correspond with the data of experiments and show, that in a phase of acceleration (g_r > 0) on a channel surface develop hydrodynamical RT-istabilities, that in a phase of deceleration transform into ground waves like gravitational waves on deep water. The maximum values of an increment of instability represent from $1.7{\cdot}10^6$ s^{-1} (R1) up to $0.7{\cdot}10^6$ s^{-1} (R3, R4). Such values of an increment exist at the first 0.5 s from a beginning of discharge, mechanisms of depressing further switch on and the growth rate of amplitude decreases. Average values of marginal amplitudes of perturbations A_{lim} in a phase of acceleration of discharges for k =100 cm^{-1} are presented in the table (where U_0 is applied voltage, L is inductance of an electric circuit, T_{acc} is the period of oscillation.

Type of EPD	U_0	L	T_{osc}	A_{lim}		
				(5)	(6)	(7)
	kV	μH	μs	mm	mm	mm
R1	30	0,47	2,2	0,2	7,7	10
R2	20	0,47	3	0,25	7	12
R3	10	0,47	6	0,16	4,5	8
R4	30	1,55	5,8	0,1	11	4

The most probable mechanism of limitation of excitation is a variation of an ablation pressure at the expense of a modification of width to a transitional full-sphere (5), at which width of 0.4-1 mm this mechanism restrains amplitude of perturbations at a level, which was observed in the experiments (0.2-0.5 mm). Other considered mechanisms do not reduce in the important limitation of amplitudes of perturbations. But the mechanism of limitation at the expense of screening radiation by walls (6), owing to quadratic dependence from wavenumber, can appear for small-scale perturbations. Coefficients of depressing is proportional to the rates of the contribution of an energy in discharge. Because of that in discharges with high energy input the saturation of perturbations starts earlier and is reached at smaller amplitudes. It explains the results of experiments with high energy rate discharges (initial applied voltage more than 40 kV), in which has not pressed to register perturbations, which exceed the distinguished ability of experimental equipment.

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