DYNAMICS OF THE CORROSION CRATER FORMATION ON THE SURFACE OF A SOLID SUBSTANCE BY POWER PULSE IRRADIATION

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The influence of a destructive laser pulse on the surface of a solid substance has been considered. The partial differential equation, which describes the formation of a corrosion crater on the surface of a hard target, has been derived. The dynamics of the pressure in the plasma-gas torch stimulated by the pulse laser radiation has been shown to affect the formation of a crater substantially. The asymptotic analysis of the "crater" equation gave reasons to assert that the adopted model of surface destruction is adequate to the actual dynamics of the formation of a crater.

1. Introduction

The mechanisms of corrosive destruction stimulated by the action of the laser radiation on the surface of a solid substance have not been completely elucidated til now.

The main characteristics of the pulse laser radiation that are important for the procedure of determining the stability of materials under the action of pulses are the intensity, the period, the pulse shape, and the radiation frequency. Pulses of high intensity and proper duration, when striking the surface of a solid substance, induce substantial damages to this surface. Therefore, they attract a special interest [1–5]. The "behavior" of condensed media subjected to high-power laser pulses is ambiguous. The formation of a corrosion crater on the surface of such a medium depends on both the power flow parameters and the properties of the specific substance.

This work is aimed at studying theoretically the dynamics of the crater formation and all the accompanying processes. In the case of destruction under real conditions, the removal of a substance from the solid phase and its transfer into the gaseous one can occur not only directly from the surface in the form of individual atoms, but also through microclusters and microdrops which cannot but be formed in the gaseous phase. Therefore, our model of this destructive process was developed on the basis of the system of inhomogeneous equations of the mechanics of continuum media [6].

2. System of equations for the crater formation dynamics

In work [8], in view of [7] and with regard for the influence of the radiation flow, the boundary conditions at the interface of two phases — the solid phase which is designated by the superscript soland the gaseous one without any index — were obtained in the following form:
— the mass flow balance equation

$$\rho_s\left(\boldsymbol{v}_s\cdot\boldsymbol{n}\right)-\rho_s^{\mathrm{sol}}\left(\boldsymbol{v}_s^{\mathrm{sol}}\cdot\boldsymbol{n}\right)=0, \tag{1}$$

— the momentum flow balance equation

$$P_s n_i+\frac{1}{c}\left(\boldsymbol{n}\cdot\boldsymbol{q}_s\right)+$$

$$+\rho_s\left(\boldsymbol{n}\cdot\boldsymbol{v}_s\right)\left(v_s^i-\left(v^{\mathrm{sol}}\right)_s^i\right)+\left(P_{ij}^{\mathrm{sol}}\right)_s n_j=0, \tag{2}$$

— and the energy flow balance equation

$$\left(\boldsymbol{n}\cdot\boldsymbol{v}_s\right)\left(\rho_s H_s+\rho_s\frac{v_s^2}{2}\right)+L_0\left(\boldsymbol{n}\cdot\boldsymbol{q}_s\right)-$$

$$-L\lambda_s(\boldsymbol{n}\cdot\,\mathrm{grad}\,T)_s+\left(\boldsymbol{n}\cdot\boldsymbol{v}_s\right)\rho_s\varphi_0=0. \tag{3}$$

In the boundary conditions (1)—(3), U_s is the specific internal energy of the continuous medium, ρ its density, $\boldsymbol{v}$ the vector of convective velocity, $\boldsymbol{n}$ the vector normal to the phase interface, $\left(P_{ij}^{\mathrm{sol}}\right)_s$ components of the stress tensor at the surface; v_s^i and $\left(v^{\mathrm{sol}}\right)_s^i$ are the i-th components of the velocity vectors of the gaseous and condensed media, respectively, at the surface; $\boldsymbol{q}_s$ is a portion of the flow that reaches the surface, the quantity $-\lambda_s(\mathrm{grad}\,T)_s$ determines the surface portion of the thermal flux in the gaseous phase; L_0 and L are the generalized loss factors at the passage of the light and thermal fluxes, respectively, through the medium–gas interface; H_s is the Gibbs function (enthalpy), φ_0 is the specific heat of the condensate—gas phase transition, and P_s the near-surface pressure. The subscript s marks quantities which are evaluated at the phase interface, where the width of the near-surface layer in each medium is substantially narrower than the radiation wavelength (of about 4000 Å).

All the boundary conditions were written down in the local coordinate frame located at the interface between the condensed medium and the gaseous phase in the region of pulse action. It is clear that, if the solid surface is not being destroyed, the reference frame remains fixed with respect to an observer. Otherwise, the reference frame becomes rigidly fixed to some point in the destruction region on the solid surface and moves together with it. That is, such a system describes events occurring immediately at every point of the surface. Hence, there appears a necessity to establish relations between the local and laboratory coordinate systems. The latter is fixed with respect to both the surface before its destruction and the central point of the transverse cross-section of a stimulating radiation beam.

The crater shape at every fixed time moment t is determined as $z(t) = S(t, x(t), y(t))$ [9]. Here, $S(t, x(t), y(t))$ is the function describing the surface of the crater formed (at every moment, it corresponds to a certain dependence of z on x and y). Below, this function will be referred to as the "crater shape function".

Converting the coordinates from one reference frame to another, we obtain the following relations for the velocity components in them:

$$v^{(\xi)} = \frac{v^{(x)} + S_x v^{(z)}}{T},$$

$$v^{(\eta)} = \frac{-S_x S_y v^{(x)} + T^2 v^{(y)} + S_y v^{(z)}}{NT},$$

$$v^{(\zeta)} = \frac{-S_x v^{(x)} - S_y v^{(y)} + v^{(z)}}{N}, \tag{4}$$

where the notations $S_x \equiv \partial S/\partial x$, $S_y \equiv \partial S/\partial y$, $N \equiv \sqrt{1 + S_x^2 + S_y^2}$, and $T \equiv \sqrt{1 + S_x^2}$ are used, and $v^{(i)}$ are the components of the velocity vector in the laboratory ($i = x, y, z$) or the local ($i = \xi, \eta, \zeta$) reference system.

Relations (4) allow one to change from the reference frame, in which conditions (1)—(3) were written down, to the laboratory one, in which the processes occurring at a destructive treatment are monitored. Owing to those transformations, the dynamic equation of crater formation in the latter reference frame can be derived. For this purpose, let us take advantage of the mass flow balance equation (1). In the local reference frame, this condition can be written down immediately in the form

$$\rho_s v_s^{(\varsigma)} = \rho_s^{\mathrm{sol}} v_s^{\mathrm{sol}(\varsigma)}. \tag{5}$$

As concerns the near-surface values of the velocity $v_s^{(\zeta)}$ and the density ρ_s, they can be determined from the system of equations, which describes a continuous gas medium, if the density ρ and the convective velocity are considered to be the functions of the pressure P:

$$\begin{cases} P_t + \left(\boldsymbol{v} + \dfrac{\rho}{\rho'}\boldsymbol{v}'\right) \cdot \operatorname{grad} P = \dfrac{R}{\rho'}, \\ P_t + \left(\boldsymbol{v} + \dfrac{\boldsymbol{v}}{(\boldsymbol{v}\cdot\boldsymbol{v}')\,\rho}\right) \cdot \operatorname{grad} P = \dfrac{(\boldsymbol{v}\cdot\boldsymbol{f})}{(\boldsymbol{v}\cdot\boldsymbol{v}')}, \\ P_t + (\boldsymbol{v} + \kappa P \boldsymbol{v}') \cdot \operatorname{grad} P = \dfrac{PR}{\rho} - (\kappa - 1)\operatorname{div}\boldsymbol{Q}. \end{cases} \tag{6}$$

Here, $\boldsymbol{Q}$ is the generalized energy flow in the medium, P the pressure that acts upon the system, $P_t \equiv \partial P/\partial t$ its partial derivative with respect to time, R the mass source-drain function related to the presence of mass sources and drains in the bulk of the gaseous phase (microclusters and microdrops that emerge at the evaporation of the solid substance into the gaseous phase [6]), f the specific density of the force exerting by radiation on the gaseous substance flow [10], and κ the polytrope index.

System (6) is compatible if

$$v_s^{(\zeta)} = \frac{P_s^{\sigma}}{\sigma\sqrt{\kappa a}}, \quad \rho_s = a P_s^{\eta} \tag{7}$$

and reduces in this case to the single equation

$$P_t - \frac{\alpha}{\gamma}\sqrt{\frac{\kappa}{a}}\, P^{\sigma}\,(\boldsymbol{n}\cdot\operatorname{grad} P) = -\kappa \operatorname{div}\boldsymbol{Q}\,\vartheta\,(\tau - t)\,. \tag{8}$$

In Eq. (7), we used the notations $\sigma \equiv (\kappa - 1)/(2\kappa) \equiv \gamma/(2\kappa)$ and $\eta \equiv 1/\kappa$ (7), and a is an integration constant. In this sense, the left-hand side of Eq. (5) may by regarded as a definite function of time and coordinates. As to the right-hand side, since $z(t) = S(t, x(t), y(t))$, the velocity component $v_s^{\mathrm{sol}(z)}$ is evidently equal to $dz/dt \equiv v_s^{\mathrm{sol}(z)} = S_t + S_x v_s^{\mathrm{sol}(x)} + S_y v_s^{\mathrm{sol}(y)}$. Substituting the obtained relations into Eq. (4) and projecting the resulting equation onto the surface, we find the component $v_s^{(\varsigma)}$ in the form

$$v_s^{\mathrm{sol}(\varsigma)} = S_t/N. \tag{9}$$

Now, substituting Eq. (9) into the right-hand side of Eq. (5) and Eqs. (7) into its left-hand side and performing some transformations, we obtain

$$\frac{\partial S}{\partial t} = \frac{2\sqrt{a\kappa}}{(\kappa - 1)\rho_s^{\mathrm{sol}}} P_s^{\beta} \sqrt{1 + S_x^2 + S_y^2}, \tag{10}$$

where $\beta \equiv (\kappa + 1)/(2\kappa) \equiv \alpha/(2\kappa)$. It is Eq. (10) that describes the dynamics of the corrosion crater formation. The near-surface pressure, which enters into the equation obtained, is not constant. To find it, one should use the boundary condition (3) together with Eq. (8) projected onto the surface [11],

$$P_t = -\frac{2a^{3/2}\kappa^2\alpha\varphi_0}{\gamma^3 bL}P_s^{2\eta+\sigma} - \frac{2\sqrt{a}\kappa^3\alpha^2}{\gamma^5 bL}P_s^{2\beta+\sigma}+$$

$$+\frac{1}{N}e_q\vartheta_\tau\frac{a\alpha\kappa^{3/2}q_{\rm in}L_0}{\gamma^2 bL}P_s^{\eta} + \kappa a^{3/2}q_{\rm in}P^{\eta+\beta}h(\omega)e_q\vartheta_\tau. \quad (11)$$

Equations (10) and (11) can be expressed in terms of the dimensionless pressure Π, time θ, crater shape function Σ, and coordinates X and Y by substituting

$$P = P_o\Pi, \quad t \equiv t_o\theta \quad S \equiv S_o\Sigma, \quad x \equiv S_oX, \quad y \equiv S_oY\,, \quad (12)$$

where P_o, t_o, and S_o are the corresponding scale factors. Three of four coefficients of the powers of Π in Eq. (11) can be put to unity at the expense of three indefinite parameters t_o, P_o, and a. Again, the single coefficient of the power of Π in Eq. (10) can also be put to unity owing to the indefinite parameter S_o. Therefore, after all transformations, we obtain the system of dimensionless coupled partial differential equations, which can be named, conventionally, the equation of crater dynamics,

$$\Sigma_\theta = \Pi^\beta\sqrt{1+\Sigma_X^2+\Sigma_Y^2}\,, \quad (13)$$

and the equation of near-surface-pressure dynamics,

$$\Pi_\theta = (-1+\Lambda e_q\vartheta_\tau)\,\Pi^{\beta+\eta}-$$

$$-\Pi^{\beta+1} + \frac{1}{\sqrt{1+\Sigma_X^2+\Sigma_Y^2}}e_q\vartheta_\tau\Pi^\eta, \quad (14)$$

where the notations $\Pi_\theta \equiv \partial\Pi/\partial\theta$, $\Sigma_\theta \equiv \partial\Sigma/\partial\theta$, $\Sigma_X \equiv \partial\Sigma/\partial X$, and $\Sigma_Y \equiv \partial\Sigma/\partial Y$ are used.

In Eq. (14), the parameter e_q determines the ratio of the flux q_s that reaches the substance surface and the initial flux $q_{\rm in}$; i.e., in dimensionless units, $e_q \equiv q_s/q_{\rm in} = f(X,Y)\exp\left(-\Lambda M\Pi^{\eta+\beta}\Sigma\right)$, where the function $f(X,Y)$ determines the transverse profile of the stimulating pulse and inserts the additional dependence on X and Y into Eq. (14), $\Lambda = \dfrac{bL\gamma^3 q_{\rm in}}{2\kappa\alpha\varphi_0}h(\omega)$ is the parameter that governs the intensity of the interaction between the evaporated substance and the incident radiation, the dimensionless parameter M is determined by the equality $M \equiv \dfrac{q_{\rm in}\gamma^2L^2}{2\varphi_0^{3/2}\kappa^2\rho_s^{\rm sol}\alpha^{1/2}}$, and ϑ_τ is the Heaviside step function. It is clear that, if the surface is being destroyed, the formation of a corrosion torch near the surface of the substance would substantially affect the factor e_q towards its reduction ($0 \le e_q \le 1$).

3. Asymptotic "Behavior" of the Crater Shape Function

Generally speaking, Eq. (14) should be split into two others, which describe the processes essentially different from each other. The first one describes the dynamics of the pressure in the course of the pulse action onto the surface $\vartheta_\tau = 1$:

$$\Pi_\theta = (\Lambda e_q - 1)\,\Pi^{\beta+\eta} - \Pi^{\beta+1} + \frac{1}{N}e_q\Pi^\eta\,. \quad (15)$$

The second one traces the behavior of the near-surface pressure after the pulse action terminates:

$$\Pi_\theta = -\Pi^{\beta+\eta} - \Pi^{\beta+1}\,, \quad (16)$$

where $N \equiv \sqrt{1+\Sigma_X^2+\Sigma_Y^2}$. Since Eq. (13) includes the pressure, it is clear that the crater formation consists of two stages. The function Π in Eq. (13) is given by the solution of Eq. (15) on the first stage and by the solution of Eq. (16) on the second.

In order to analyze the asymptotic time "behavior" of the crater formation dynamics, which is the main purpose of this work, it is convenient to consider the phase curves of the dependence $\Pi_\theta(\Pi)$ making use of Eqs. (15) and (16) (see Fig. 1,*a*). The quantities e_q and N depend on both the time and the crater shape; therefore, in order to study the phase curves (trajectories), we will examine the situation when the width of the incident beam is much greater than the crater's depth and the beam intensity is distributed uniformly over its transverse cross-section. This enables us to assume $N = 1$ both in Eq. (15) and in crater equation (13). As was mentioned above, the value of e_q varies in time within the interval from 0 to 1. Therefore, consider some characteristic values. The value $e_q = 0$ means that, owing to absorption, the flux $q_s = 0$, i.e. the initial flow does not reach the surface. In this case, the pulse ceases to influence this surface even if it still continues. Mathematics also verifies this to be true: Eq. (15) automatically acquires the form of Eq. (16) (Fig. 1,*b*; curve $e_q = 0$). From this viewpoint, consider the limiting case $e_q = 1$ (no absorption) and one of the intermediate cases for Eq. (15). All the above-indicated restrictions by no means concern Eq. (16), because the parameters N and e_q are absent from it.

Arrows in Fig. 1 denote directions of the pressure development in time: the first stage (I) starts from point

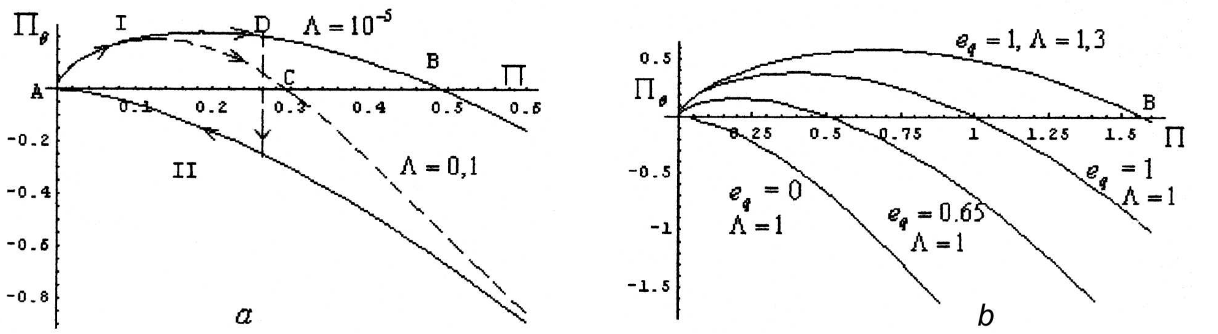

Fig. 1. Phase trajectories of two stages described by Eq. (15): (a) curves I corresponds to Eq. (15) at $N = 1$ and $\Sigma \approx 1$, and curve II to Eq. (16); (b) curves for Eq. (15) at various e_q and Λ

A, which is unstable on this stage (the derivative Π_θ is positive); therefore, the dependence $\Pi_\theta(\Pi)$ changes along curve I up to the moment of pulse termination (designated by point D in Fig. 1,a) or to the moment, when pressure becomes maximal (points B or C in Fig. 1,a). Those points are stable: as soon as the curve crosses the Π axis, the condition $\Pi_\theta < 0$ becomes satisfied. This forces the process to return back to point B (or C). At those points, the gas pressure remains finite until the pulse terminates. As soon as the pulse terminates, the transition onto curve II occurs, and the phase point of the process moves along the curve until the pressure reaches zero. Figure 1,a also displays the dashed curve which conventionally describes the dynamics of the process in the case of large Λ (the growth of this parameter physically means an enhancement of the interaction between radiation and the plasma-gas torch formed near the surface of the substance). It is evident from Fig. 1,b, that, if $e_q \approx 1$, there exist such values of Λ that values of the pressure Π are larger than unity at point B. Moreover, if e_q is constant, the growth of Λ is accompanied by the growth of the maximal value of Π_θ (cf. two curves in Fig. 1,b which correspond to the $e_q = 1$ case).

As was noted, the zero point is stable at the second stage of the process (see Fig. 1,a). Therefore, in order to estimate the asymptotic behavior of the crater formation dynamics after the pulse terminates, it is sufficient to study the behavior of Σ, taking into account only the term with the lowest power of Π in Eq. (16), i.e. to consider the equation $\Pi_\theta = -\Pi^{\beta+\eta}$. Then, we obtain $\Pi = ((\beta+\eta-1)\,\theta)^{-\frac{1}{\beta+\eta-1}}$. The integration constant in the expression for Π was put equal to zero, because $\Pi \to 0$ both at large times and at the initial moment of the pulse action. As far as we work in the approximation $N = 1$, Eq. (13) reduces to the form $\Sigma_\theta = \Pi^\beta$. Therefore, the asymptote of the function Σ can be determined by solving the equations

$$\Sigma = D_2(X,Y) + \frac{1}{\eta-1}\left((\beta+\eta-1)\,\theta\right)^{\frac{\eta-1}{\beta+\eta-1}} =$$

$$= D_2(X,Y) - \frac{(2+j)}{2}\left(\frac{j-1}{2+j}\theta\right)^{-\frac{2}{j-1}}, \qquad (17)$$

where $D_2(X,Y)$ is the quantity independent of time; j the number of degrees of freedom in the gas, which is coupled with the polytrope index κ by the relation $\kappa = (j+2)/j$ (for ideal gas, $j = 3$). In dimensional units, the crater shape function $S \sim D_2(x,y) - 1/(\rho_s^{\rm sol})(\varphi_0/tq_{\rm in})^{\frac{2}{j-1}}$ [12], where $D_2(x,y) \equiv S_0 D_2(x/S_0, y/S_0)$ is the integration constant.

The determination of the asymptotes of Σ in terms of the number of degrees of freedom j explicitly demonstrates the strict negativity of the power of θ, which testifies for the slowing down of the crater growth and, in due course, the total termination of its formation. Thus, after the pulse action terminates, the crater shape function Σ will fall down following the power law, which is the asymptotically correct behavior. The dynamics of the crater formation rate, which decreases after the pulse action terminates, is depicted in Fig. 2 for various values of j.

For the time interval, which does not exceed the period of the radiation pulse (Eq. (15)), the dynamics of crater formation at the initial moment is also determined by the term with the lowest power η (i.e. $\Pi_\theta = \Pi^\eta$), which actually dominates either within the whole interval or till the moment when the phase trajectory (Fig. 1,a) arrives at point B. Thus, the asymptotic "behavior" of the crater formation at the beginning of the destructive process is governed by the power law

$$\Sigma = \frac{2\theta}{3+j}\left(\frac{2\theta}{2+j}\right)^{\frac{1+j}{2}}. \qquad (18)$$

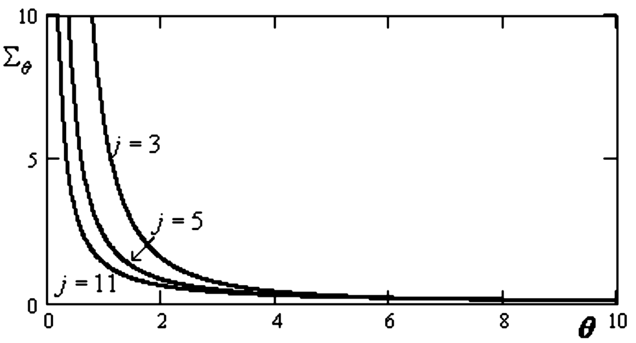

Fig. 2. Dynamics of the crater growth slowing down after the pulse action terminates

In the dimensional form, the crater shape function S is proportional to $(q_{\text{in}}t/\varphi_0)^{1+\frac{1+j}{2}}$.

The case where the pressure acquires its maximal value (points B and C in Fig. 1) should be studied separately. At these points, the derivative $\Pi_\theta = 0$, which corresponds to the pressure that is fixed in time. Then, the equation for the crater shape function, or the rate of crater formation, is determined as follows:

$$\Sigma_\theta = \Pi_c^\beta \,. \tag{19}$$

Whence, it follows that the crater shape function is described by the linear dependence $\Sigma = D(X,Y) + \Pi_c^\beta \theta$, where $D(X,Y)$ is the integration constant. That is, the growth of Σ in time is slower in comparison with dependence (18).

As is seen from Fig. 1,*a*, if the factor e_q is taken into account consistently, the maximal value of the dimensionless pressure most likely does not exceed unity. But a possibility for the situation $\Pi > 1$ (the upper curve in Fig. 1,*b*) to be realized cannot be excluded absolutely. Then, the dynamics of crater formation changes, because, at $\Pi > 1$, the term with the highest power of Π, rather than that with the lowest one, dominates in Eq. (15). In this case, the equation for the pressure looks like $\Pi_\theta = -\Pi^{\beta+1}$, and the corresponding asymptotic dependence of Σ on time is determined by the logarithmic dependence

$$\Sigma = D_1\,(X,Y) + \frac{(2+j)}{1+j}\ln(\theta)\ , \tag{20}$$

i.e. becomes even slower.

In Fig. 3,*a*, the asymptotes are shown for the $\Sigma(\theta)$ dependence given by Eq. (18); they evidence for the explosive character of the crater formation. At the same time, Fig. 3,*b* illustrates the dynamics of solution (20) which demonstrates a slower growth of the crater. In the case of dependence (18), the response of the quantity Σ to the external laser action at the beginning of the destructive process is faster for larger numbers of degrees of freedom j. For dependence (20), on the contrary, the crater is formed more slowly at higher j's.

The displayed figures give reason to assert that the process under consideration has an explosive, power-like in θ, character at the start of the crater formation, and that the dynamics changes linearly after the pressure having achieved its maximal possible value (point B in Fig. 1,*a*). As soon as the laser pulse terminates, the process of crater formation stops very quickly (Fig. 4).

Figure 4 illustrates the crater formation dynamics using its asymptotes. The first section (I) reproduces the crater formation process at the beginning of the surface destruction (Eq. (18)). The second one (II) shows the dynamics, when the pressure approaches its maximum. The last section (III) illustrates the variation of the crater shape after the pulse terminates.

In the case $\Lambda > 1$, the explosive process (Fig. 3,*a*) gradually transforms first into logarithmic one and then becomes linear.

In order to analyze how rapidly the rate of the crater formation changes if the radiation absorption by the gaseous medium is taken into account, we averaged the pressure over the pulse action period in the case where $\kappa \to 1$ during the pulse. Since the equation for the crater formation dynamics looks like

$$\Sigma_\theta = \bar{\Pi} \tag{21}$$

in this approximation ($\kappa \to 1$), the changes of the crater formation rate on the surface of the solid substance during the action of the laser pulse can be illustrated graphically (Fig. 5). It is evident that, owing to the absorption of radiation by the plasma-gas medium, the crater formation rate reaches its maximum rather quickly and, afterwards, starts to fall down, even before the action of this pulse terminates. In this case, the value $\Lambda = 10^{-10}$ corresponds to the magnitude of the absorption factor k of the order of 10^2 cm^{-1}, and the value $\Lambda = 10^{-15}$ to k of the order of 10^{-3} cm^{-1}. The plots in Fig. 5 and equality (21) testify that the maximal value of the dimensionless pressure is about 0.5. Therefore, its dimensional value, according to Eq. (21) is $P = 0.5P_0$. The parameter P_0 can be evaluated by the data of work [12]. The magnitude of the pressure P is proportional to the radiation intensity; therefore, we estimate it for fluxes $q_{\text{in}} \sim 10^{14}$ W/cm^2 and the sapphire surface as $P \sim 10$ TPa, which is in agreement with experimental data.

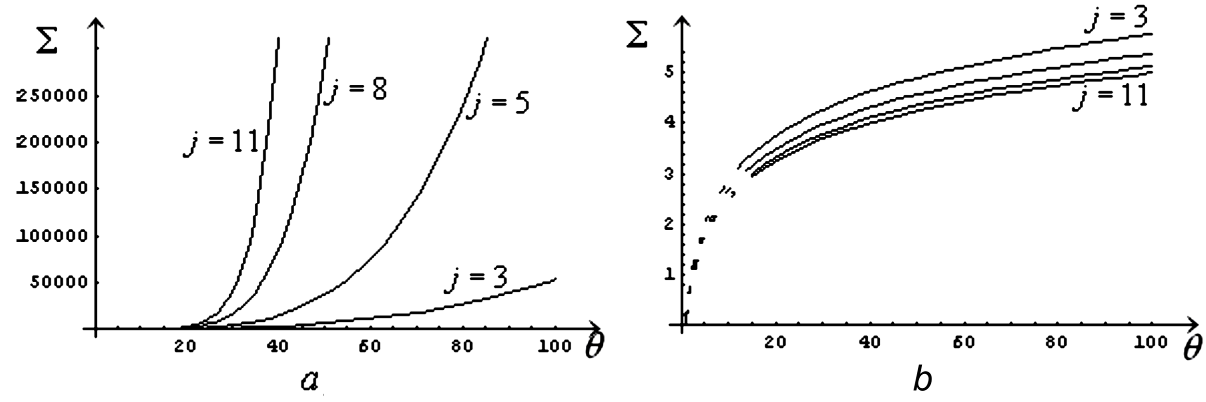

Fig. 3. Asymptotic behavior of the crater formation function in the case of a high-power laser pulse acting on the surface

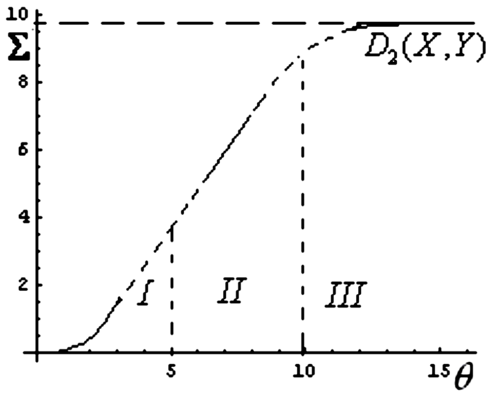

Fig. 4. Schematic time dependence of the crater formation dynamics under the influence of laser radiation

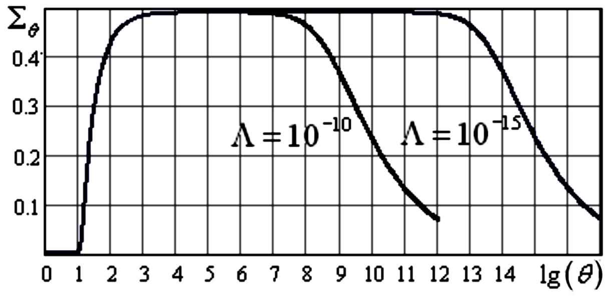

Fig. 5. Changes of the crater formation rate in the course of the laser pulse action for various parameters of the interaction Λ between radiation and a plasma-gap medium

4. Conclusions

The dynamics of the formation of a corrosion crater on the surface of a solid material at the destructive treatment of the latter with pulse laser irradiation has been considered. This dynamics, being the main object of our researches, is determined by condition (1) which reduces to the differential equation (10) or its dimensionless counterpart (13). Since the latter equation depends on the pressure, Eq. (14) is analyzed simultaneously.

The phase diagrams of this equation (Fig. 1) have been analyzed. The parameters Λ and e_q, which determine the interaction between the incident radiation and the plasma-gas torch, have been demonstrated to affect the crater formation dynamics substantially. In particular, a decrease of the pressure, owing to that interaction, is accompanied by a decrease of the crater formation rate (Eq. (19)). This slowing down is proportional to the pressure to some power β $(0.8 \leq \beta < 1)$. Since the parameter e_q decreases in time, there is a probability for the crater formation process to stop even before the laser pulse terminates if this pulse is long enough.

The asymptotic estimations of the crater development dynamics have been carried out. The function of the crater's surface shape has been shown to stabilize in time for an arbitrary polytrope index after the pulse action terminates. This evidences for the internal consistency of the model.

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ДИНАМІКА УТВОРЕННЯ КОРОЗІЙНОГО КРАТЕРА НА ПОВЕРХНІ ТВЕРДОЇ РЕЧОВИНИ ПІД ДІЄЮ ПОТУЖНОГО ІМПУЛЬСНОГО ВИПРОМІНЮВАННЯ

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Р е з ю м е

Розглянуто задачу руйнівного імпульсного впливу на поверхню речовини. Було отримано диференціальне рівняння в частинних похідних, що описує динаміку утворення корозійного кратера на поверхні твердої мішені. Показано, що на формування кратера істотно впливає динаміка тиску плазмово-газового факела, ініційована імпульсним лазерним впливом. Асимптотичний аналіз “кратерного” рівняння дає підстави стверджувати, що прийнята модель процесу руйнування поверхні відповідає реальній динаміці утворення кратера.