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EROSION LASER TORCH IN THE LIGHT OF THE GATING RADIATION FROM AN AUXILIARY LASER

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A gating laser illumination pulse has been used to visualize different stages of the formation of the liquid-drop phase formed by the hydrodynamic mechanism in the erosion laser torch of a metal. Analysis of the sequence of photographs obtained under different irradiation conditions has been performed.

Introduction. It is known [1–7] that under the action of a laser radiation of moderate power density (10^6–10^8 W/cm^2) the erosion torch consists of vapors, plasma, and particles of the liquid-drop phase of the target material. Initially small liquid droplets (20–100 nm) formed by the volume vaporization get into the erosion torch [2, 7–9]. At the end of the laser pulse larger particles (1–100 μm) formed by the hydrodynamic mechanism get into the torch [10–13].

From the point of view of increasing the speed of cutting metals, it is expedient to use cutting conditions with maximum carrying out of liquid drops, since the great bulk of the metal ejected into the erosion torch is determined by the hydrodynamic mechanism. On the other hand, in modern laser technologies the liquid-drop phase of the material is in many cases an undesirable factor. Therefore, it is necessary to study the formation dynamics of the liquid-drop phase of the target material by the hydrodynamic mechanism in order to attempt to control this phenomenon or, at least, take it into account.

Formulation of the Problem. Under the action on metals of a laser pulse in the free-running mode fairly large liquid-drop particles (dozens of microns) are formed by the hydrodynamic mechanism practically from the very beginning of the laser pulse. These particles can be registered in high-speed photographs in the light of either the plasma torch or the laser (if the laser radiation wave length is in the spectral sensitivity area of the apparatus [1]). Particles of the liquid-drop phase of the target material not only scatter, but also absorb the laser radiation transmitted through the erosion torch.

However, if metal targets are subjected to the action of a squared laser radiation pulse with a sufficiently high spatial-temporal homogeneity and with a sufficiently large irradiation area (when the diameter of the erosion hollow is much larger than its depth), then it is possible to separate in time the small particles formed by volume vaporization and the large ones formed by the hydrodynamic mechanism, which only appear at the end of the laser pulse. Since at this time there is no illumination by the laser or plasma radiation, these particles are usually invisible for experimenters.

To study the dynamics of such particles, it is expedient to make use of the radiation from an auxiliary laser. The basic requirements for studying such probe radiation are that the radiation wavelength be in the spectral sensitivity area of the recording apparatus and the laser pulse duration be much shorter than the characteristic dynamic processes in the erosion laser torch (10^{-6} sec).

Experimental. The general scheme of the experiment on studying the dynamics of liquid-drop particles formed by the hydrodynamic mechanism in the light of the gating radiation from an auxiliary laser is shown in Fig. 1. In the present work, a target from aluminum alloy D16T was exposed to the radiation from a high-energy laser facility based in neodymium-activated glass working substances. The basis of the facility is a master laser with a confocal cavity that permits obtaining a quasi-stationary lasing pulse of duration up to 1.5 msec, from which a squared lasing pulse of duration from 50 to 500 μsec is cut out by a mechanical shutter. Then this pulse is amplified by two optical quantum

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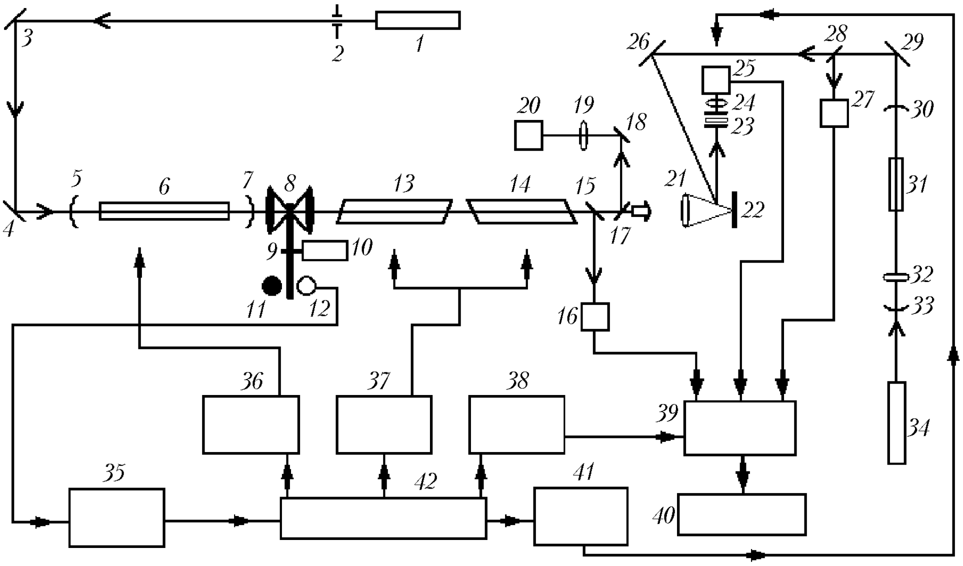

Fig. 1. General scheme of the experiment: 1, 34) alignment laser; 2) diaphragm; 3, 4, 26, 29) deflecting mirrors; 5, 7) spherical mirrors; 6) working substance of the driving generator; 8) system of two cofocusing lenses; 9) rotating diaphragm; 10) electric motor; 11) lock-in tube; 12) firing photodiode; 13, 14) amplifiers; 15, 17, 18, 28) rotating plates; 19, 21, 24) lenses; 16, 27) photodiodes; 20) calorimeters; 22) target; 23) optical filters; 25) CCD matrix camera; 30–33) ruby laser components; 32) optical filter; 35–38, 41) pulse generators; 40) computer; 42) controlling generator.

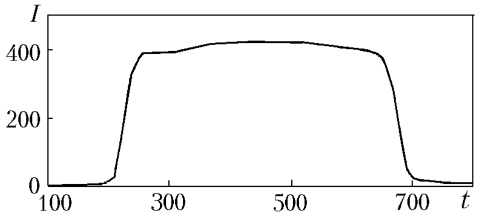

Fig. 2. Time form of the acting laser pulse. t, μsec.

amplifiers. The laser and the amplifiers are based on standard GOS-1001 M heads. The time form of the acting laser pulse is shown in Fig. 2. The high-energy laser facility is described in more detail in [14].

A ruby laser in the monopulse mode of duration ~50 nsec was used as a probe laser. Q-switching was carried out by means of a phototropic shutter. Image recording in the light of the ruby laser radiation (λ = 694.3 nm) was performed with the use of a digital camera based on a CCD matrix. The remaining radiation was cut off spectrally by a set of glass and interference filters placed before the camera lens. Data acquisition, storage, and processing are automated and computer-controlled. To provide the required operating time of a particular unit of the experimental facility, we used a rather complex timing system based on a multichannel generator of delayed sync pulses. The purpose of all components of the general scheme of the experiment is given in the caption to Fig. 1.

Varying the delay time of the ruby laser pulse permits obtaining images of the erosion laser torch at different instants of time and thus makes it easy to follow the evolution of the torch.

Goncharov et al. [15] have investigated in the light of the radiation from a free-running ruby laser the erosion torches of targets from aluminum A99, aluminum D16T, and Bi under the action of them of a quasi-stationary neodymium laser pulse of duration 1.5 msec. The pulse had an axisymmetric bell shape with a steeper leading edge and a small-angle trailing edge. In this case, up to the moment the laser pulse maximum is reached, mainly a highly disperse phase (10–100 nm) gets into the erosion torch, and as the intensity of the acting laser pulse decreases, larger

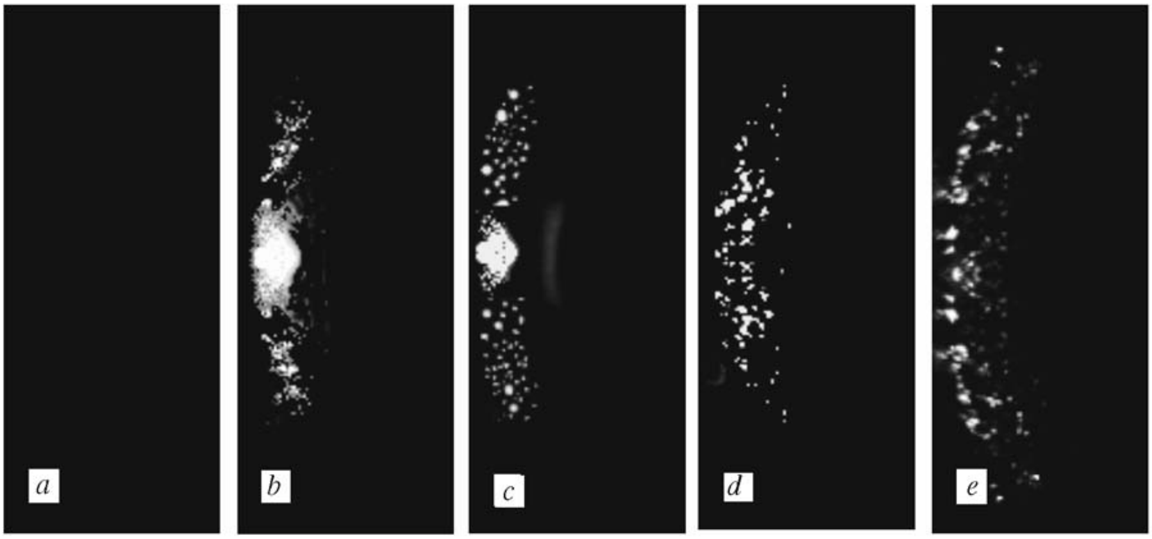

Fig. 3. Photographs of the liquid-drop phase of the erosion laser torch (irradiation spot diameter 10 mm) taken at different instants of time after the moment the laser pulse intensity began to decrease: a) $\Delta t = 0$; b) 170; c) 260; d) 350; e) 450 μsec.

particles (1–100 μm) formed by the hydrodynamic mechanism begin to go into the erosion torch. During a large part of the irradiation time, particles formed by both mechanisms are present in the erosion torch and interact with the laser radiation incident on the target and the torch plasma. All this is well illustrated by the experiments described in the article. However, since the character of the interaction with the radiation of small and large particles is different, it is desirable to carry out experiments with separated mechanisms of particle formation.

In the present appear, this has been achieved by exposing a target from aluminum alloy D16T to a squared pulse of the radiation from a neodymium laser. The pulse duration was 450 μsec (see Fig. 2). The diameter of the irradiation spot on the target surface was 10 mm, and the power density of the neodymium laser radiation in the irradiation spot was $1.4 \cdot 10^6$ W/cm^2. The hollow depth upon irradiation was ~0.3 mm.

Figure 3 shows the images obtained in the light of the gating ruby laser radiation. The exposure time of each image was ~50 nsec. The zero time was assumed to be the instant at which the intensity of the squared pulse of the neodymium laser radiation began to decrease.

As is seen from Fig. 3a, at the moment that the intensity of the laser radiation pulse begins to decrease, liquid drops formed by the hydrodynamic mechanism do not get into the erosion torch yet. It is also seen from the photograph that, unlike [15], we excluded background lights (from the plasma, the pump lamps, etc.) from the experiments by using not only glass but also interference filters. Liquid drops formed by the hydrodynamic mechanism appear only some time after the neodymium laser radiation pulse intensity begins to decrease, and, as is seen from the sequence of images, the torch widens with time. It should be noted that the target destruction products in the form of rather large particles escape at a small angle with the target surface in the form of a cone, and the opening of the cone therewith (~155^{o}) practically remains unchanged in the course of time. This indicates that during the recording time the shape of the solid edges of the hollow and its depth also remain unaltered, i.e., under the action of the recoil momentum, when the laser radiation intensity decreases, the whole of the liquid layer of the metal begins to move from the center of the hollow to its edges and splashes out at an angle determined by the depth of the hollow and the shape of its edges.

Processing of the photographs shown in Fig. 3 has made it possible to determine the velocity of motion of drops. At the beginning of motion they have a velocity of ~50 m/sec, and then it decreases to 25 m/sec. These results are in good agreement with the data of [15].

To elucidate the dynamics of the liquid phase from an erosion hollow in which the diameter and the depth are commensurable, we varied the focusing of the acting neodymium laser. In so doing, a spot of diameter ~5 mm

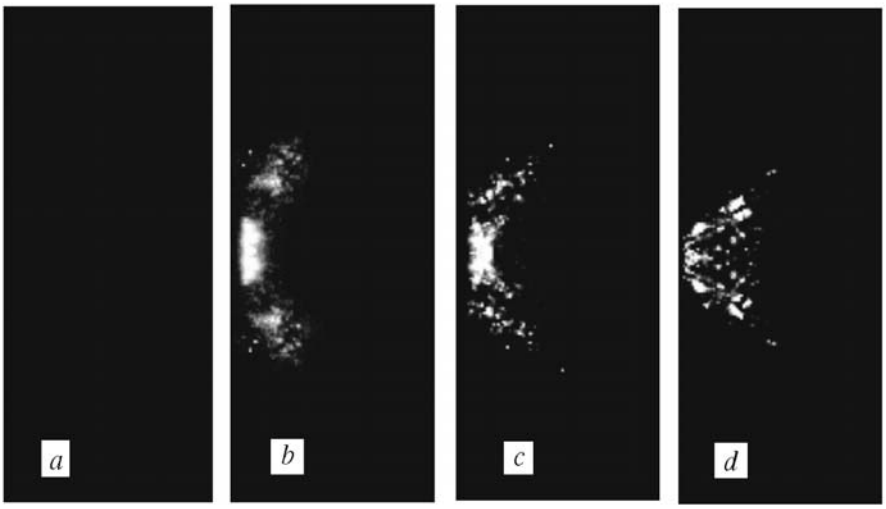

Fig. 4. Photographs of the liquid-drop phase of the erosion laser torch (irradiation spot diameter 5 mm) taken at different instants of time after the moment the laser pulse intensity began to decrease: a) $\Delta t = 0$; b) 30; c) 250; d) 450 μsec.

was illuminated on the target surface. In this case, the radiation power density reached $1.7 \cdot 10^7$ W/cm^2. The hollow depth upon irradiation was ~0.6 mm.

At such power densities of the laser pulse the intensity of evaporation and volume vaporization is much higher than in the case of focusing the laser radiation into a spot of diameter 10 mm. Due to this, in the course of time the erosion hollow has a greater depth. Therefore, liquid droplets formed by the hydrodynamic mechanism should escape at a larger angle with the target surface.

The results of the experiments are presented in Fig. 4. As follows from Fig. 4a, at the instant of time at which the intensity of the neodymium laser radiation pulse begins to decrease large drops do not yet appear, but after some time (see Fig. 4b) it is seen that large drops get into the erosion laser torch, and the angle between the direction of their escape and the target surface is greater than in the previous experiments. This points to a stronger influence of the hollow walls on the mechanical trajectory of liquid drops in this experiment.

Processing of the experimental results has made it possible to determine the velocities of motion of particles. Initially, they reach ~100 m/sec and then decrease to 25 m/sec. This points to the fact that inside the hollow a higher pressure is realized due to the increase in the laser radiation intensity.

Results and Discussion. As is seen from Fig. 4, in the course of time the angle between the trajectory of escaping particles formed by the hydrodynamic mechanism and the target surface increases. It should be emphasized that now neither the laser radiation nor the plasma radiation are present; however, the hollow depth increases with time. This point to a gradual ousting of the liquid phase formed during the laser action by the recoil momentum upon a sharp decrease in the laser pulse intensity. Such dynamics of the laser erosion products can be explained by the liquid metal viscosity.

Thus, with the aid of a monopulse of the illuminating (probe) pulse of a ruby laser we have visualized the nonluminous laser erosion products and studied the dynamics of their expansion.

The experiments on the investigation of the dynamics of the liquid-drop phase formed under the action of a squared laser radiation pulse on metals have shown that under our conditions liquid drops formed by the hydrodynamic mechanism begin to get into the erosion torch only after a decrease in the laser radiation intensity. With large irradiation spots, when the erosion hollow diameter is much larger than its depth, liquid drops escape at a small angle with the target surface (varying slightly with time), and the recoil momentum therewith ousts the liquid throughout the thickness.

With smaller irradiation spots, when the diameter of the erosion hollow is commensurable to its depth, the liquid-drop phase of the target material formed by the hydrodynamic mechanism also appears only after a decrease in the laser radiation intensity. However, it escapes at a larger angle with the target surface and this angle grows with time. This points to a gradual deepening of the hollow in the absence of both the radiation and the plasma, which is probably connected with the value of the liquid metal viscosity in the irradiation area.

Conclusions. Taking into account the fact that small (nanosized) liquid-drop particles of the target material getting into the erosion torch during the acting laser pulse move perpendicularly to the target surface, the results of the present investigation can be used for spatial separation of small particles formed by volume vaporization and large particles formed by the hydrodynamic mechanism.

NOTATION

I, relative intensity of radiation; *t*, time, μsec; λ, radiation wavelength, nm.

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