The influence of the temporal shape of a fiber laser radiation pulses in the process of destruction the shell explosive objects

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Abstract. This article is devoted to the process of remote exposure to the radiation of fiber laser on metal shell explosive objects. The advantages of fiber lasers that allow their use in demining complexes are described. The paper presents an experimental study of the effect of fiber laser radiation profiled and non-profiled pulses on metal simulators of explosive objects. It is established that the effect of profiled pulses compared to the non-profiled allows to significantly reduce the melting time of the sheath and to decrease the required laser energy.

1. Introduction

The development of laser physics and the processes physics of laser radiation interaction with matter allows today to identify a number of promising applications of remote laser exposure [1, 2]:
– cutting and welding of hard-to-reach metal structures;
– minerals extraction;
– fight against aircraft of different functional purpose;
– the clearance of various explosive shell objects.

The latter task is particularly relevant today both from a practical and theoretical point of view, since in most cases the neutralization of explosive objects requires its without detonation neutralization. In addition, the development of this direction is due to the wide introduction of modern domestic fiber lasers into various technologies [3].

Fiber lasers have been developed relatively recently, but are already used in various fields along with traditional solid-state lasers, and in some cases replace them. This is due to a number of fiber lasers advantages [4]:
– relatively high efficiency, 25-30%);
– ability to create high-power emitters (up to 100 kW) by combining the radiation of several fiber laser modules into one;
– compact and easy to maintain and repair due to low heat transfer, which does not require intensive cooling;
– the possibility of the radiation transmission in the optical waveguide.
Today on the basis of domestic technological fiber lasers, production of STA "IRE-Polyus", specialized complexes of laser neutralization of various shell explosive objects are created [3].

2. The experiment description
However, the effectiveness of such complexes depends on both the energy parameters of the laser radiation and the modes of action (pulse repetition rate, pulse duration and shape).

The most important task of optimizing the parameters of the acting radiation is to ensure the regime of high-speed the shell penetration. In this case, the high rate of laser destruction of the shell minimizes the heating the explosive time. The latter is extremely important because the thermal energy initiates combustion of the explosive growth of the internal pressure and the detonation development.

Optimization of these parameters should be carried out taking into account the specifics of the processes variety occurring in the laser effect zone (melting, evaporation, thermal softening of the material, the effect on the shell internal pressure of the combustion explosives products) [5].

The paper investigated the effectiveness of the pulsed-periodic radiation impact of ytterbium fiber laser, mass-produced by STA "IRE-Polyus" on metal simulators of shell explosive objects with internal pressure acting on the shell.

Laser radiation using a mirror-lens optical system was focused on a shell made of structural steel 20. During the experiment, the time of drilling through holes in the shell was recorded at different the laser pulses parameters.

When implementing laser demining technology to improve the efficiency of laser action on the shell and reduce the time of thermal impact on the explosive, it is required to implement a regime of high-speed removal of the melt without significant energy costs for the material evaporation. One of the key processes that ensure the high-speed removal of the melt from the zone of influence is the action of the steam recoil reactive forces.

In this regard, the paper proposes an approach based on the functional separation of the laser pulse action, which is a combination of a long high-energy pulse and a short high-intensity pulse-spike. Thus, the action of the pulse is divided into two stages: intensive melting, which is provided by a long high-energy pulse section, and the subsequent removal of the melt due to the intensification of the recoil vapor pressure, with the help of an acting high-intensity short pulse- spike [6]. Control of the time form of the fiber laser radiation pulses was carried out using specialized software "LaserNet".

In the experiment, the shell objects were exposed to profiled and non-profiled in time form pulses of fiber laser radiation. The radiation parameters were as follows: duration and pulse repetition rate of 3 ms and 50 Hz, respectively, the average power of 2.5 kW.

3. Experiment results and discussion
The experimental results showed that the use of laser pulses with a complex (profiled) time form allowed to reduce the penetration time of the metal shell (thickness 4 mm) of the object by 2,3 times (from 35 to 15 s), compared with the impact on the shell of pulses of classical (non-profiled) form of similar energy. At the same time, the radiation energy expended on melting under the influence of profiled pulses is reduced from 87.5 kJ to 37.5 kJ compared to the effect of non-profiled pulses. Similar energy and time ratios were observed for other investigated objects with shell thickness from 3 mm to 5 mm.

The dynamics of the process of melting the metal shell of the object by laser pulses with a complex time form is shown in figure. 1.
Figure 1. Laser penetration dynamics of the metal object shell

The thermal action mechanism of laser radiation on materials is described by the heat equation, according to which the deepening of the thermal wave front after the action of the laser pulse on the shell is determined by the formula [7]:

$$h = \sqrt{a \times \tau}$$

\(a\) – coefficient of thermal diffusivity of the shell material, \(m^2/s\); \(\tau\) – the duration of the radiation pulse, s.

In light of the presented formulas and the obtained results of the experiment found that the duration of the thermal front in the explosive substance when exposed to a shaped pulse is reduced 4.3 time (from 26 C to 6 C) compared to the influence of unshaped pulses (for steel shell with a thickness of 4 mm).

According to the results of the experiment, it was found that the optimization of the time form of the acting laser pulses reduces the time of the metal shell through penetration, while reducing the time of thermal action on the explosive, which is necessary for the implementation of the laser detonation-free neutralization mechanism.

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