Holographic interferometry for the study of an electric explosion of titanium wires

A S Skryabin, A V Pavlov, A M Kartova and V D Telekh

Department of Power Engineering, Bauman Moscow State Technical University, 5/1 2nd Baumanskaya Str., Moscow, 105005, Russia

E-mail: terra107@yandex.ru

Abstract. The paper presents the results of a slow (with a characteristic process time \( \tau \approx 50–100 \mu s \)) electric explosion (in an air medium) of thin (with a characteristic diameter \( \delta \approx 20–50 \mu m \)) titanium wires with holographic interferometry. A characteristic energy input into the wires was varied from 2.5 to 3.0 J·mg\(^{-1}\). The optical scheme of interferometry laser diagnostics was discussed. The formation of the main explosion features (shock front, explosion products, etc.) was registered. An interference shift allowed calculating of changing of a refractive index and a density in different zones of the explosion. The simplest estimations indicated that a density in shock compressed gas was varied from \(1.1\times10^{20}\) to \(2.4\times10^{20}\) cm\(^{-3}\).

1. Introduction

Double exposure laser holographic interferometry is well known and a reasonably accurate method for different processes study. In this method [1], [2], two states of the object are recorded on a photosensitive film with two exposures. When such a hologram is restored, two images of the object interference with each other, forming a holographic interferogram. At the same time, interference bands appear on the reconstructed image of the object, which characterize the change of the object at different times. If the direction of the reference beam before the second exposure is changed to a small angle, then a system of direct interference fringes arises. Those fringes are curved at the places where the registered object changes between exposures. The period of the reference bands is determined by the angle of rotation of the reference beam.

An electric explosion [3, 4] of thin (with characteristic diameter \( \delta \approx 20–50 \mu m \)) metal wires [5] is one of the processes which we can study with holographic interferometry. In this work, a slow [5, 6] electric explosion (with a characteristic energy input time \( \tau \approx 50–100 \mu s \)) of titanium fibers was experimentally studied. That mode can lead to the formation of micron particles, as it was found out in work [7, 8].

2. Experimental set

A detailed description of the experimental setup for study of the process of a slow electric explosion was presented in [7]. The experiments were carried out with titanium wires (a characteristic diameter \( \delta \approx 20–50 \mu m \) and with an initial resistance \( R_0 \approx 7–20 \text{ Ohm} \)). Their length varied from 75 to 90 mm. The capacitor charging voltages (capacitance \( C_0 = 0.6 \text{ \mu F} \)) were \( U_0 = 2.5–7.0 \text{ kV} \). A thyatron (PulseTech, Ltd.) was used as a managed circuit switcher.
The upgraded optical scheme of double exposure laser holographic interferometry is presented in figure 1.

![Optical scheme of double exposure laser holographic interferometry](image)

Figure 1. Optical scheme of double exposure laser holographic interferometry diagnostics: 1 – laser (Nd-YAG, λ=532 nm); 2 – translucent mirror; 3 – beam expander; 4 – titanium wire; 5 – wedge; 6 – screen; 7 – lens system; 8 – interference filter.

The generation of a laser beam was performed with laser 1 (Nd-YAG with λ = 532 nm). Further, this beam passed through the system of mirrors 2 and was divided into two beams (objective and reference). The reference beam passed through a system of mirrors and lenses 7, after which it hit the screen 6, on which the photosensitive film was located. The object beam passed through the lens system 7 and entered the expander 3 to obtain a collimated beam with dimensions sufficient to visualize the entire area of the explosion of the wire 4. Two exposures of electric explosion recorded on a photosensitive film on the screen 6. The number of interference fringes was regulated by the angle of rotation of the wedge 5. To visualize the inhomogeneities of the fluxes and cut off the parasitic illumination, an interference filter 8 was used (with λ_{max} = 532 nm and Δλ = 11 nm).

3. Results and discussions
Typical holographic interferometry picture of exploding wire is shown in figure 2. There were visualized a generated shock wave front (1) [9], a shock compressed gas area (2) and an extended high temperature explosion products (3). Different direction of interference fringes in founded areas could be explained by the complex composition of the explosion products, the refractive index changes in the opposite way.

Scanned photosensitive film showed the behavior of the wire during explosion (see figure 3). The film contented a picture of initial wire before the explosion and exploding wire at the time 14 μs, so we could see wire deflection from its initial position.

Exploding wire 2 had a complicated form. There were exploding products 3 consisted of melted metal particles, fragments of wire. Initial wire 1 did not have an ideal shape in cut, it also has several defects that overheated and caused appearance of breaks 4 in wire. Fragments of wire visualized by the end of experiment. A bigger area of explosion products 5 contained vapors, overheated particles. In the mode of high energy input shock wave front 6 appears and moves with the velocity 750–800 m·s^{-1}. 
Figure 2. Typical holographic interferometry picture of titanium wire explosion at 20 μs: 1 – shock wave front, 2 – shock compressed gas, 3 – explosion products, 4 – initial wire.

Figure 3. Scanned photosensitive film of holographic interferometry picture of titanium wire explosion at 14 μs: 1 – initial wire, 2 – exploding wire, 3 – explosion products, 4 – breaks caused by overheating in defects, 5 – area of explosion products (containing vapours, overheated particles, etc), 6 – shock wave front.

For the quantitative processing of the results of interferometric studies, the algorithm [1], [10], 11] was used. For the selected interference fringe on the interferogram in the area of shock compressed gas the phase shift value was determined (see figure 4).

Depending on the change in the strip shift, gas concentration change in the region of the shock wave front was calculated and amounted [1]:

[Insert equations or additional text here if needed]
\[ \Delta N = \frac{1}{2\pi\alpha_a} \frac{\lambda \Delta k}{l} \approx 1.1 \ldots 2.4 \times 10^{20} \text{cm}^{-3}, \]

where \( \lambda \) is wavelength of laser radiation (532 nm), \( \Delta k \) is strip shift, \( \alpha_a \) is atomic polarization, \( l \) is size of the study area.

**Figure 4.** Scanned photosensitive film of holographic interferometry picture for calculating the concentration in the shock front area.

**4. Conclusion**

The work performed the results of series of experiments on the “slow” explosion of titanium fibers. An explanation of the complex structure of the conductor during the explosion was obtained on the basis of double exposure laser holographic interferometry pictures. The main areas were identified: explosion products, shock compressed gas, shock wave front. In the area of the shock wave gas concentration change was calculated.

**Acknowledgments**

This work was performed using research facilities cluster “Beam-M” (BMSTU).

**References**

[1] Loktionov E Yu et al 2013 Devices and experiment technique 1 53
[2] Nosov K V et al 2018 J. Phys.: Conf. Ser. 1115 032011
[3] Surkaev A L 2014 Technical Physics Letters 40 23
[4] Surkaev A L 2015 Technical Physics 85 37
[5] Chace W G and Moore H K 1962 Exploding wires (New York: Plenum Press) p 360
[6] Ivanenkov G V et al 2004 The basic processes of electric explosion of conductors in a vacuum (Preprint FIAN No 9)
[7] Skryabin A S et al 2019 J. Phys.: Conf. Ser. 1250 012018
[8] Skryabin A S et al 2018 J. Phys.: Conf. Ser. 1115 042017
[9] Ternan J G 1986 Physics Letters A 115 230
[10] Kuzenov V V, Ryzhkov S V and Polyakov K V 2018 20th International Symposium on High-Current Electronics p 46
[11] Kuzenov V V, Ryzhkov S V and Shumaev V V 2015 Problems of Atomic Science and Technology 98 53