Combination of the velocity interferometer system for any reflector and the photon Doppler velocimetry methods to study transparent and absorbing condensed matter

T V Kazieva$^{1,3}$, K L Gubskiy$^{1,3}$, A P Kuznetsov$^{1,3}$, I Yu Tishchenko$^{1,3}$, R D Glukhov$^{1,3}$, V A Pirog$^{1,3}$, S Yu Ananev$^{2}$ and L I Grishin$^{2}$

1 National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe Shosse 31, Moscow 115409, Russia
2 Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
3 Limited Liability Company “Laser Eye”, Kashirskoe Shosse 31, Moscow 115409, Russia

E-mail: glizerogen@gmail.com

Abstract. The paper proposes a method for combining photon Doppler velocimetry and a system of speed interferometers for any reflective systems, which allows one to study the behavior of transparent media under the action of powerful shock waves without the use of additional reflective surfaces. The paper presents the results of an experiment on the propagation of a shock wave in water. In this experiment, water was an absorber; however, the proposed method would also work provided that the test material is transparent and provides reflection.

1. Introduction

Currently, the most common way to study the strength properties of a material is the shock-wave loading technique under high-speed collisions. This is realized with the help of powder guns, light-gas accelerators, accelerators based on condensed explosives, and electromagnetic accelerators. A distinctive feature of this technique is the creation of a shock wave with nearly flat front. This allows us simplifying the processing of experimental data and using one-dimensional thermodynamic models.

In studies of the shock-wave processes, each experiment is unique in its own way and has a number of hardly reproducible parameters. The main thermodynamic parameter available for measurement in these experiments is the mass velocity. A large number of registration channels increases the information content of the experiment, as well as the reliability of the data obtained by controlling the parameters of the experiment responsible for the adequacy of the assumptions used in the calculations.

There is a large number of methods for measuring the mass velocity of a substance, which differ in the principle of action. One of the most popular methods for diagnosing a material in an extreme state is unequal arm interferometry (velocity interferometer system for any reflector—VISAR) [1] and direct optical heterodyning (photon Doppler velocimetry—PDV) [2].
Figure 1. Scheme of a shock-wave experiment with the combined measurement using KDNI 532-7 and KIVI.

Despite the fact that these methods are competitors and both enable velocity measurements in a similar range, there are certain experiments where their combination allows obtaining additional information about the state of the shock-loaded substance.

In this work, the systems KDNI-532-7 [3] (implemented using the VISAR method) and KIVI [4] (implemented using the PDV method) were used. Purpose of this work is to demonstrate the possibility of studying materials with low reflection coefficient in the visible or near-ir range.

The device KDNI-532-7 uses laser radiation with a wavelength of 532 nm, while KIVI uses 1550 nm. Both devices have fiber-optic routes to deliver radiation to a target fixed in an explosion chamber, and back to signal processing units (figure 1). In the case of the KDNI-532-7 system, the radiation is focused on the target using a specially designed sensor. The radiation reflected from the object is introduced into the interferometric unit by an input optical fiber bundle consisting of seven QQ 200/220 optical fiber cables, which allows measuring the object displacement at several points simultaneously. KDNI-532-7 includes two interferometers that have different lengths of delay lines: coarse (interferometer constant 1280 m/s/period) and fine (280 m/s/period). In KIVI system, a gradient lens with an antireflection coating with a focal length of 5 cm is used for focusing.

Signals from photodetectors are fed to oscilloscopes, which record the received signal. The velocity data is derived from the signals recorded by the oscilloscopes using special software that is different for each system.

2. The results of experiments with combined measurements
Interferometric studies of the strength of liquids under pulsed tension and compression require that a thin layer of reflective material (for example, aluminum foil) be present on the surface of transparent test substances when assembling the samples [5]. This may lead to ambiguous results or different interpretations of experimental data.

In this paper, a method is proposed that allows investigating materials with low reflectance in the visible or near-ir range. This can be useful in the study of both absorbing and transparent substances. To demonstrate the capabilities of this method, an experiment was conducted to study the shock wave propagation through water. In the experiment, PDV and VISAR methods
were used together. The scheme of the experiment, where two systems were used simultaneously, is presented in figure 2.

The absorption coefficient of the radiation used in PDV (at a wavelength of 1550 nm) in water is $6.8 \text{ cm}^{-1}$, therefore, the reflection recorded by the PDV system corresponds to the reflection only from the water surface (the reflection coefficient is 4%) (figure 3). The laser radiation used in VISAR (532 nm) passes through water and is reflected from the metal surface. The graphs show that the movement of the metal surface begins at approximately 21 $\mu$s. After about 2 $\mu$s, the shock wave reaches the surface of the water and the PDV velocity measurement is made. After the shock wave leaves the Al in the water, an unloading wave from the free surface of
Figure 4. Shock adiabats of aluminum and water: \( W \) is the velocity of the Al impactor.

the impactor comes to the boundary, and the speed will fall more than 1 km/s. Subsequent circulation of the compression and rarefaction waves will lead to a stepped discharge. At 27.5 \( \mu \)s, water reaches the sensors and destroys them.

When the shock wave exits from aluminum screen into water, state 1 is realized (figure 4). After about 0.5 \( \mu \)s, an unloading wave arrives at the boundary from the free surface of the impactor (more precisely, from the boundary between explosion products and aluminum impactor). In this case, the speed will fall more than 1 km/s (state 2). Subsequent circulation of compression and rarefaction waves will lead to step unloading.

In this experiment, water was an absorber; however the proposed method would also work provided the test material is transparent, its refractive index is high enough to provide a reflection coefficient from the surface of the order of a few percent, and the reflections from other surfaces behind the transparent object are absent.

3. Conclusion
The presented method allows studying materials with low reflection coefficient in the visible or near-ir range. In addition, the combination of two methods with use of the both VISAR and PDV instruments simultaneously enhances reliability and accuracy of the temporal dynamics data of the mass velocity.

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