Two-channel interferometer system of direct optical heterodining for destruction by shock waves processes studying

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Abstract. The article describes a multichannel modular system for velocity measurements in shock physics. The two-channel time compression system is based on PDV method. It was tested in lead dusting experiments.

1. Introduction
Research of shock wave processes under strong pulse loadings of targets is one of the actual problems of high-energy-density physics [1]. Particle velocity is one of the few parameters available for direct measurement. Due to the extremes of the experimental conditions, contactless methods of its diagnostics are preferable. The only contactless and time continuous method of velocity measurement is laser interferometry.

One of the most common and actively developing systems for measuring particle velocity is VISAR (Velocity Interferometer System for Any Reflector). Developed in the early 70s, VISAR system undergone many modifications that significantly increased its accuracy and reliability. VISAR technique allow to measure velocities of various studied objects surfaces in shock-wave experiments in a large range of speeds (50-10000 m/s) [2]. However, such interferometers also have certain disadvantages. This technique does not allow to measure the speed of several objects localized at one point. In addition, this type of system has a time resolution limit, which restrict the range of possible measurements.

Figure 1. Scheme of the basic diagnostic system using the PDV technique.
In order to research fragmentation and dusting of objects (i.e. registration of several objects simultaneously) PIV (Particle Image Velocimetry) technique is used. However, PIV allows to measure only the average velocities of the studied particles. Continuous velocity measurements can be conducted using PDV (Photonic Doppler Velocimetry) methods. Scheme of the basic diagnostic system using the PDV technique is shown in Fig. 1. Similar measurement system was used in research of the processes of chondritic targets destruction under high-power laser radiation on SATURN facility [3].

The principle of operation of this system is following: beam of a single-frequency continuous laser is transported to the target via a fiber optic cable. After passing through the circulator, the beam is divided into two parts. First beam hits the target, reflects from its moving surface and returns into the GRIN lens. After passing through the circulator, the light reflected from the object is added to the second beam that has passed through the attenuator. As a result of mixing of these two signals, shifted in frequency due to the Doppler effect, the photodetector generates beats, which subsequently registered by an oscilloscope. The speed is obtained by recalculating using the following equation:

\[ V = \frac{\lambda}{2 f_b} \]

where \( \lambda \) – probing radiation wavelength, \( f_b \) – beats frequency.

At a speed of 1 km/s, the beat frequency \( f_b = 1.29 \) GHz. To measure such speeds, it is required that the detection system has a bandwidth of the order of several GHz.

In this manner, it is possible to measure the velocities of all reflecting particles. This technique is immune to external influences, accurate, easy to implement [4,5].

2. System description
Each shock physics experiment is unique in its own way and has a number of hardly reproducible parameters. Increasing the number of registration channels allows to increase not only the information content of the experiment, but also the reliability of the obtained data. Latter is performed by controlling the experiment parameters responsible for the adequacy of the assumptions used in the calculations. An increase of the detected points amount allows to study the particle velocity behavior of several objects simultaneously (or several points of the same object), and also to measure the shock wave parameters before its interaction with the target along with estimation of the wave front flatness.

Increasing the number of registration channels for PDV based devices is complicated by the high cost of the wide-band (capable to record signals in the several GHz band) recording systems. However, application of the time compression technique provides the possibility of several optical channels registration without increasing the amount of the photoelectron conversion channels and analog-digital conversion channels [6].

The time compression implies a more efficient use of the time base of the oscilloscope, due to which it becomes possible to record signals corresponding to two different points of the object. The implementation of the technique is based on the two optical recording channels forming by the splitter with the subsequent delay of light in one of them by the delay line (Fig. 3). When the light from the
second channel passes the delay line, the signal of the first one is recorded. After that the fast fiber switch changes its state and sends light from the second channel to the photodetector.

![Figure 3](image_url)

**Figure 3.** Scheme for the implementation of a time compression.

The memory capacity of the oscilloscope allows to record several signals in succession, with these signals displayed sequentially on the chart.

3. Experimental setup

For the research of the shock-wave loading processes under explosion load two-channel diagnostic system was developed, its scheme is shown in Fig. 4. This scheme was obtained by upgrading the original basic one (Fig. 1) by adding time delay unit in measuring arm (Fig. 3). The length of the delay line corresponds to 25 μs signal delay, the response time of the switch is ~ 300 ns.

![Figure 4](image_url)

**Figure 4.** Scheme of a two-channel fiber interferometer with direct conversion of the optical signal with a time compression.

To increase the reflected signal power, in front of the mixer an AEDFA–PA–35 fiber amplifier was built into the scheme. Also, to cut off its noise a filter with a central wavelength of 1550.86 nm and a bandwidth of 0.5 nm, was used. Fiber laser radiation tunable in wavelength from 1550.5 nm to 1550.9 nm was used as a probe radiation. The signal was recorded using an ET–3500AF photo sensor (9 GHz band) and a LeCroy WaveRunner 640 Zi oscilloscope (4 GHz band).

The developed measurement system is a combination of optical and electronic elements assembled into several interconnected blocks. Diagram of the system components is shown in the Fig. 5. One optical unit allows to measure the speed at two points of the object. The modular configuration of the system assumes that with an increase of the optical blocks number to four, it will be possible to measure the speed at eight independent points. The 2W laser was estimated as sufficient to work with 4 optical units simultaneously. The last element of the complete assembly is four-channel oscilloscope.
Developed two-channel PDV system was tested in the study of dusting in the xenon atmosphere during shock wave loading of solid targets (Fig. 6). Lead samples were used as targets. Irregularities with parameters ≈45 μm, ≈300 μm were applied to the surface by the pressurized matrix in order to ease cumulative effects occurrence.

In order to process experimentally obtained interferograms software based on short-time Fourier transform was developed in MATLAB computing environment [7]. During processing the signal is multiplied by a window function of a fixed length. Fourier transform of resulting dependency is taken, which is assigned to a given point in time. The result of processing is a set of spectrograms corresponding to different points in time. Calculation according to the following equation must be made to obtain the dynamics of the object velocity from the spectrum (1). The time and velocity resolutions are determined by the processing parameters such as window function size.
Fig. 7 shows an example of a signal recorded during an experiment and its spectrogram. During the process of target velocity measurement dusting of the bottom surface of the sample was observed, which is displayed on the spectrogram. In this case, the signal from the first GRIN lens corresponds to the time interval 1. In interval 2, the system recorded the signal from the second GRIN lens.

4. Conclusion
Measurement system based on a two-channel PDV interferometer for the study of processes of dusting and the destruction of solid targets was developed. The system has a modular composition and can be expanded to up to 8 channel applications. Using the developed measurement system test experiments on dusting of lead under shock loads were conducted.

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