Vernier laser diagnostic system for velocity measurements at Angara-5-1 facility

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Abstract. The report presents a laser diagnostic system designed to analyze the behavior of a matter in extreme states and the propagation of shock waves. The research system consists of a pair of velocity interferometer systems for any reflector (VISAR), push pull and conventional VISARs, forming a vernier scheme. This configuration was designed for Angara-5-1 facility. Test experiments of metal plate acceleration using magnetic field were carried out. The velocities up to 6 km/s were obtained.

1. Introduction

Shock-wave experiments are currently the main tool used to obtain empirical data necessary for constructing equations of state at high pressures. One of the most convenient and accessible diagnostic parameters for extreme states is the velocity of matter free surface. There are a large number of different installations that provide a high speed of the impactors. Explosive lenses and light gas guns are actively used at the moment for accelerating of a flat impactor at speeds of the order of 4–6 km/s. Nanosecond scale lasers create a pressure of several Mbar and speeds of the order of 20 km/s, but they have a small area of influence (about 1 mm²) and a non-uniform character of the shock wave generated. For acceleration of large (about several cm²) samples to speeds of the order of 10 km/s, acceleration by a magnetic field is used. Installations such as Angara-5-1 provide magnetic pressure of current with a linear density of more than 10 MA/cm with rise time about 200 ns [1]. It is a promising tool for shock-wave experiments in Mbar pressure range.

A planar load geometry is preferable in shock-wave experiments [2, 3]. It allows using a one-dimensional mathematical analysis and ensures the unambiguity of the load magnitude. The flatness of the impactor flight is determined by parameters of installation and impactor. In this case, it is necessary to control the temporal dynamics of the impactor, the spatial distribution of its velocity, as well as the state of aggregation and the integrity of it. This task required the development of diagnostics, which allows continuously and remotely with a time resolution of the order of ns to observe the object of loading. It can be done by laser interferometry.
2. Experimental setup

The Angara-5-1 installation is capable of generating voltage up to 1.5 MV and current up to 6 MA. When such currents pass through a system of conductors, a strong magnetic field is created under the influence of which the flyer breaks out of the electrode material at a speed of about 10 km/s. Such a flyer can be used as an impactor in shock physics experiments. The experimental design for acceleration of the metal flyer is presented in figure 1.

In this assembly, current flows from the anode to the cathode through a metal rod. In this case, the anode section with a height of 6 mm and a thickness of 1 mm through which current flows in the direction opposite to the current in the rod is pulled out. On the experimental installation described above, shadowgraph registration system was organized [4]. Three-frame shooting allows calculating average velocity of the impact or during acceleration. However, it is impossible to determine exactly how the sample was destroyed. At the same time, often the blurring of the object boundary after the start of movement could be explained by the destruction of the sample. To fully describe the impactor dynamics and its integrity, it was necessary to organize a continuous measurement of velocity in time. To solve this problem, it was decided to use the velocity interferometer system for any reflector (VISAR) method. Shock waves investigation on Angara-5-1 installation was carried out using two installations: push pull VISAR and conventional VISAR, forming a vernier scheme [5].

The experimental setup is schematically shown in figure 2. Laser radiation with a wavelength of 532 nm is transported via a 50 m optical fiber from a noise-free room to a target using a collimator, a mirror and a collecting lens. Diagnostic window of lithium fluoride (LiF) was used in the experiment for sample destruction preventing. The radiation reflected from the target is divided into two equal parts. One of these parts is assembled into a collimator and transported over an optical fiber 50 m long to the push-pull VISAR, located in a noise-free room. The second part of the radiation is directed to the conventional VISAR, which is located near (about 10 m) of the chamber. The recording equipment of conventional VISAR is protected from electromagnetic interference by a steel casing, the protection of the photomultiplier from bremsstrahlung is organized by lead plates.

3. Experimental results

The purpose of the experiments was to develop a method for monitoring the state and velocity of an impactor, using interferometric diagnostic complex. To compare the data obtained from interferometric diagnostic complex with shadowgraph registration system a series of experiments was carried out to measure the speed of an aluminum flyer, which was accelerated by the Angara-5-1 high-current pulse.

A typical time dependence of the velocity is shown in figure 3. The surface velocity of the flyer with lithium fluoride was approximately 5.5 km/s. Since the dynamic impedance of Al is
close to the dynamic impedance of LiF, it means that the velocity of the impactor before collision was approximately 2 times higher. Obviously, sharp acceleration and deceleration during 1 µs
stand out sharply on the graph. The nature of the velocity dynamics behind the shock-wave front is determined by the interaction of the magnetic field with the flyer and requires additional studies [6]. The velocity profile of the conventional VISAR has sharp stepwise changes, which have a noise character and some quasi-periodic interferences that could arise due to the pressure induced birefringence in the LiF crystal. Since a polarizing prism is used at the optical input of a continuous VISAR, induced birefringence could introduce some error in measuring the phase difference [7]. The velocity profile of the push pull VISAR does not have such changes due to depolarizing properties of the optical fiber through which the radiation from the object was transported. The record length was 6 µs, at the end of which there is a jump in speed caused by shock wave exiting from the LiF crystal. From this point in time, a loss of signal is observed on the velocity profile obtained from conventional VISAR, which may mean destruction of the LiF crystal. The results from the two interferometers are in good agreement.

4. Conclusion

A diagnostic system was built based on combination of push-pull and conventional VISARs in vernier scheme. Test experiments of metal plate acceleration using magnetic field were carried out. The velocities of the order of 6 km/s were obtained.

References

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