Application of K008 Camera within Measuring Complex of Laser Diagnostics of Shock and Detonation Waves

Vitali B. Lebedev [a], Grigory G. Feldman [a], Maksim A. Karpov [a],
Aleksey V. Fedorov [b], Aleksey V. Menshikh [b], Dmitriy V. Nazarov [b],
Stanislav A. Finyushin [b], Valeriy A. Davidov [b]

[a] All-Russian Research Institute of Optical and Physical Measurements (VNIIOFI), BIFO Company, Ozernaya st. 46, 119361 Moscow, Russia. Tel/Fax: (095) 437-33-88, E-mail: bifo@bifo.ru
[b] Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Mira av. 37, 607190 Sarov, Nizhnii Novgorod Reg., Russia. Tel: (831-30) 446-27, Fax: (831-30) 459-58, E-mail: root@gdd.vniief.ru

Introduction

In May 2001 the K008 camera /1,2/ being a part of a laser Doppler velocity meter (LDVM) experimental complex of the Russian Federation Nuclear Center, the All-Russian Research Institute of Experimental Physics (RFNC-VNIIEF), was tested under real conditions of gas-dynamic experiments. Some tasks typical to explosion physics were solved during these experiments: the record of velocities of the plates thrown by an explosion; the record of shock and detonation wave fronts; the record of elastic-plastic properties of constructional materials. At the same time the following camera's characteristics were checked: resistance to electromagnetic, acoustic and light interference; conformity of real characteristics to Documentation data; convenience in operation and reliability.

The results of tests and experiments

The camera has two modes of operation: a single-frame mode and a streak mode (a mode of linear sweep). A range of linear sweep coefficients provided by two interchangeable control units is from 1ns/cm to 300μs/cm (a sweep length is 2cm, a limiting temporal resolution is 20 ps). In so doing, in the single-frame mode frame duration is ranging from 10ns to 600μs (maximum frame dimensions are 15 x 20mm^2). A spatial resolution is not less than 15 l.p./mm, a spectral range is from 400 to 800nm.

The camera without an additional external electromagnetic screen was placed directly near (~10cm) the high current circuits of a solid-state ruby laser and 2m apart from a blasting chamber in which initiation of detonators is performed by a spark discharge with a voltage greater than 30kV. There was neither false triggering and nor worsening of image quality.

Thanks to correction, by means of software, of all the geometrical and photometrical distortions in both single-frame and streak modes including the light-signal characteristics and sweep nonlinearity, the accuracy of the interference lines displacement detection was essentially increased in these experiments. As a result of correction, the geometrical distortions were decreased from $4\%_{\max}$ down to not more than 1% and sweep nonlinearity was decreased from $10\%_{\max}$ down to not more than 1%. Conversion coefficient nonuniformity across an image field was decreased from $30\%_{\max}$ down to not more than 5%.

More than 50 gas-dynamic experiments were performed. The diagrams of mass velocity of various metallic plates thrown by an explosion were received (see Fig. 1).

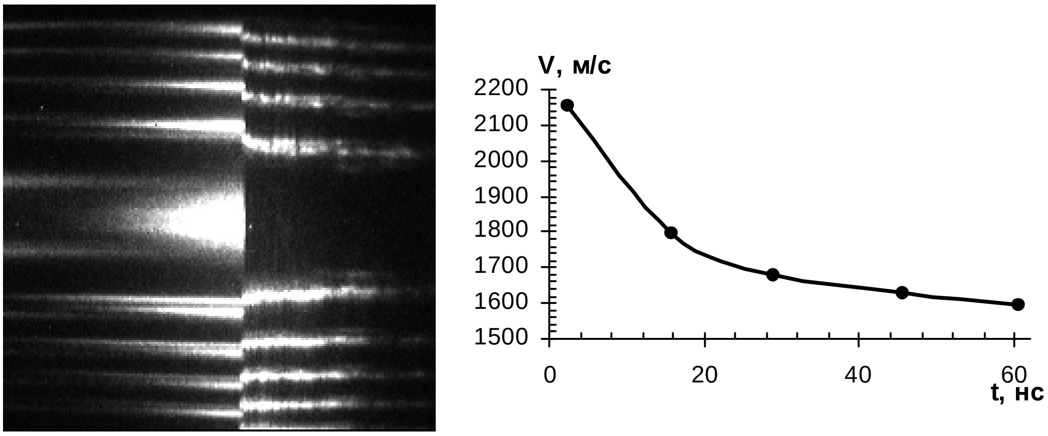

Fig. 1. A typical recorded interferogram and a diagram of a mass velocity of the aluminum plate thrown by explosion.

After these successful tests the RFNC-VNIIEF has acquired several K008 cameras. Three of them are used in the measuring complex, where investigations in the field of physics of shock and detonation waves are performed with use of a Fabry-Perot laser interferometer /3-5/. In particular, parameters of detonation of high dense explosives (HE) were recorded at arrival of a detonation wave to the interface “HE-transparent window”. A thin aluminum foil (≈10μm) was placed between HE and the window. This foil reflected laser radiation, which underwent a Doppler frequency shift due to foil motion. Figure 2 presents an interferogram of the test and the time dependence of the HE-window interface velocity for HE as trinitrotoluene (TNT) (ρ=1.633g/cm^3, D=6.93km/s) and the window made of LiF.

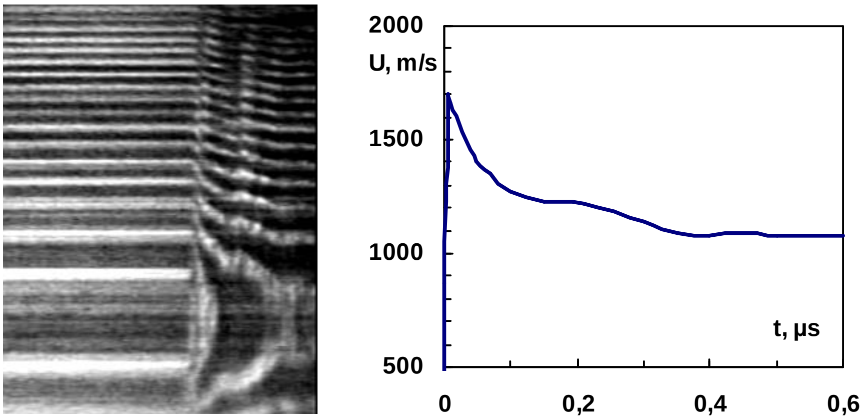

Fig. 2. Interferogram and graph U(t) in a test with TNT.

In a test with TNT, the value of a particle velocity spike U=1.73km/s was recorded at the HE-LiF interface. Using the known adiabat of non-reacted TNT D=2.57+1.88U and recalculating the spike state in LiF for the spike state in TNT, it is possible to determine the value of Neumann spike that is equal to P=24.5GPa, U=2.21km/s in TNT. The known values of Chapman-Jouguet state (C-J) for TNT obtained by various methods are within the range 17.9…19.35GPa. We take the average value P=18.6GPa. In this case, the value of the Neumann spike, which we recorded, is 1.32 times higher than the C-J state. In the graph of Figure 2, a drop of the velocity U(t) ends as a shelf. Duration of U(t) drop was Δt=320ns. This is duration of the zone of chemical reaction. Its value is in good agreement with data of the other authors /6/.

The K008 camera is used in the laser measuring complex for recording elastic-plastic and strength properties of metals. Figure 3 shows a typical interferogram and a corresponding characteristic profile of velocity of free surface of an elastic-plastic body at arrival of spall pulse to it. Due to elastic-plastic behavior of the material, unloading of the spall layer has two-stage character (an elastic precursor followed by a plastic wave).

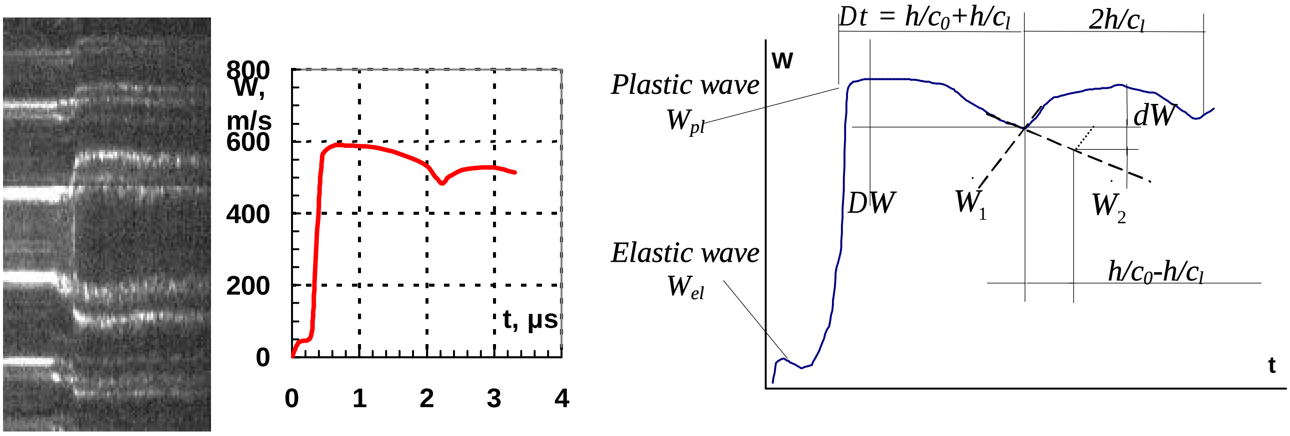

Fig. 3. A typical interferogram and a corresponding characteristic profile of the velocity of a free surface during spall fracture in an elastic-plastic body.

The formulas for determination of spall strength and the value of the elastic precursor in an elastic-plastic body are as follows /7/:

$$s_{spall} = \frac{1}{2} r_0 c_0 (\Delta W + dW) \quad (1); \qquad d\ W = \left(\frac{h}{c_0} - \frac{h}{c_l} \right) \cdot \frac{\left| \dot{W}_1 \cdot \dot{W}_2 \right|}{\left| \dot{W}_1 \right| + \dot{W}_2} \quad (2); \qquad h = \frac{\Delta t}{\left(\frac{1}{c_0} + \frac{1}{c_l} \right)} \quad (3)$$

$$s_{HEL} = \frac{1}{2} r_0 W_{el} c_l \quad (4)$$

The following designations are taken in formulas (1-4): r_0 – material density; c_0, c_l - respectively, volumetric and longitudinal sound velocities in material; s_{HEL} – value of elastic precursor; s_{spall} – spall strength; ΔW – difference between the first maximum and the minimum of velocity of free surface of spall layer (the pullback amplitude); W_{pl} – amplitude value of plastic wave velocity; W_{el} – amplitude value of elastic wave velocity; Δτ - time of occurrence of extending pulse, dW – correction, which takes account for difference between velocities of propagation of the unloading part of falling pulse and the front of spall pulse; h – thickness of spall plate; $\dot{W}_1, \dot{W}_2$- gradients of velocity of free surface, respectively, in falling rarefaction wave and in front of spall pulse (see Fig. 3).

Conclusion

So, using the Fabry-Perot laser interferometer and the K008 camera it is possible to record the following parameters in one test: amplitude values of elastic and plastic waves velocities (W_{el} and W_{pl}); ΔW – difference between the first maximum and the minimum of velocity of free surface on the dependence W(t); time of occurrence of extending pulse (Δτ). The values of elastic precursor (s_{HEL}), spall strength (s_{spall}) and thickness of spall plate (h) are calculated from relations (1-4). So, for example, these values obtained in the test (see Fig.3) were the following for Armco-iron: W_{el}=64m/s; W_{pl}=590m/s; s_{HEL} = 1.5GPa; s_{spall} = 2.67GPa; Δτ = 0.22μs; h = 0.58mm.

The K008 camera is also used within the laser measuring complex to measure velocity of acceleration of liners and plates; to determine launching capabilities of various HE, changes of the refractive index during compression of a transparent material by shock waves, etc.

The camera is very convenient in operation due to its extremely small overall dimensions and weight. It can be easily built-in practically into any optical system of already existing measuring setups without complication of their optical systems. It can be easily fastened in any position and practically in any place of both a big measuring complex and small setup. And convenience of its carrying over and transportation (what is often very important) is evident and is not to be proved. Fig. 4 shows the participants of the tests and the K008 camera in the setup of the laboratory LDVM where it was preliminarily tested. For comparison the K008 camera is set over the FER-7 camera with dimensions of a typical image converter camera. FER-7 protection against false triggering under operation conditions within the LDVM complex turned out to be a very difficult problem.

Fig. 4. The participants of the tests the K008 and FER-7 cameras.

The authors are grateful to G.M. Reitblat for development of K008 camera software.

References

1. V.B. Lebedev, G.G. Feldman, Super small single streak and single frame image converter camera, SPIE, Vol. 3516, pp. 85-91.
2. K008 Streak and Uniframe Camera, http: www.bifocompany.com
3. A.V. Fedorov et al. Detonation front in homogenous and heterogeneous HE// Proceedings of APS Conference “Shock Compression of Condensed Matter”, Snowbird, USA, 1999, pp.801-804.
4. A.V. Fedorov, A.V. Menshikh, N.B. Yagodin. //Chem Phys. Reports, 2000, vol.18 (10-11), pp.2129-2138.
5. A.V. Fedorov, A.V. Menshikh, N.B. Yagodin. // Chemical Physics (in Russian), # 11, 1999, pp.64-68.
6. S.N. Lubyatinsky, B.G. Loboiko. Detonation reaction zones of solid explosives. // Proceedings of 11 Symposium on Detonation, Snowmass, USA, 1998, pp. 836-844.

7. Kanel’ G.I., Razorenov S.V., Utkin A.V., Fortov V.E. Shock-wave phenomena in condensed matter. M.: «Yanus-K», 1996, p.408 .