Visualization of explosive field and initial combustion of detonating powder by time series interferometry

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Abstract: A pulsed YAG laser is used to ignite detonating powder to produce a explosive field and combustion field. The time series interferograms of the explosive field and initial combustion process are obtained with a time series interferometry which consists of a large aperture and long path interferometer, a series pulsed laser source and a rotating right angle prism type of high speed canning camera. These time series interferograms form the basis of studying the characteristics of thc explosive field and combustion field of the detonating powder.

点火药爆轰场和起始燃烧过程的时间序列干涉法显示

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摘要：本文利用脉冲YAG激光引燃点火药产生爆轰场和燃烧场，用时间序列干涉法来获得爆轰场和燃烧的时间序列干涉图。其中时间序列干涉法是由大口径长程干涉仪，序列脉冲激光光源和旋转直角棱镜扫描式高速摄影仪组成。这些时间序列干涉图是进一步研究点火药爆轰场和燃烧场特性的基础。

Introduction

In general because of instantaneity, destructivness and danger of explosive field, only high speed camera and high speed shadowgraphy were used to visualize the phenomenon of explosive field[1,2]. But high speed camera can only be used to record the outside form of explosive field and can not be used to visualize the internal structure of explosive field such as shock wave structure. With high speed shadowgraphy, the shock wave structure of explosive field can be observed, but the thermodynamic parameters such as temperature and density distribution can not be calculated quantitatively from shadowgrams. Interferometry is widly used to measure flow field, but still now, there are no reports on measuring explosive field by using interferometry because of adverse condition of explosive field.

In this paper, a small type of pulsed YAG laser is used to ignite a detonating powder to produce explosive field and combustion field. For visualizing the characteristics of explosion and combustion of detonating powder, a method of time series interferometry is used which is made of a large aperture and a long path interferometer[3], a serial pulsed laser source and a rotating right angle prism type of high speed scanning camera[4]. The time series interferograms of explosive field and initial combustion process are obtained. It is very useful for studying the characteristics of explosion and combustion of detonating powder.

Experiment arrangement

The experiment arrangement is shown in Fig.1. By means of an acousto-optical modulator, CW He-Ne laser is modulated into a series of laser pulses. The pulse width can be changed from 0.1 μs to 100 μs, and the pulse interval is from 1 μs to 10 ms. The serial pulsed laser is used as a testing light source of the interferometer. A beam collimating system consists of two lenses L_1 and L_2 to provide a collimated light beam of 300 mm in diameter. The interferometer is composed of two mirrors M_1 and M_2 arranged to form a long path interference cavity of 5m length. The aperture of the mirrors is 300mm in diameter. With a lens L_3, the interferograms are imaged on the film of the high speed scanning camera and recorded.

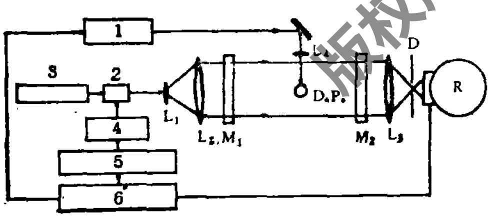

Fig.1 Experiment arrangement

1—pulse YAG laser 2—acousto-optical modulator 3—He-Ne laser 4—driver power 5—generator of serial-pulse signal 6—synchronous time-delay mechanism R—record system D—diaphragm

D. P. spherically shaped, is a new kind of detonating powder and located in the centre of the interference cavity.

The laser used to ignite the detonating powder is a small type of pulsed YAG laser. Its maximum output energy is 50mJ, wave length is 1.06μm, and pulse width is 20ns and 150ns in the conditions of Q-switch and free oscillation respectively. The output of pulsed YAG laser, serial pulsed He-Ne laser, and the shutter of the high speed scanning camera are controlled with a synchronous time delay mechanism. Pulsed YAG laser beam is focused on the detonating test ball by the lens L_4.

The large aperture and long path interferometer, especially suitable for measuring explosive field, has the properties: simple optical layout, single path and separated structure, strong resistance to vibration. According to multiple beams interferometric principle, the light intensity distribution of the interferogram is[3]

$$I = I_0 T^2 \left| \sum_{N=1}^{\infty} R^{N-1} \exp(iN\delta) \exp(-iN^3\delta_1) \right|^2 \tag{1}$$

where $\delta = \frac{2\pi}{\lambda} 2n_0 d, \delta_1 = \frac{8\pi}{3\lambda} n_0 d a^2$, T is transmissivity, I_0 is incident light intensity, R is reflectivity, N is the times of light reflection forth and back between M_1 and M_2, d is the distance between M_1 and M_2, a is a small inclination between the two mirrors.

For two adjacent fringes at x_1 and x_2, we obtain the relations

$$\frac{2\pi}{\lambda} n_0 2\alpha x_1 = 2m\pi \qquad (m = 0, 1, 2 \cdots) \tag{2}$$

$$\frac{2\pi}{\lambda} n_0 2\alpha x_2 = 2(m+1)\pi \qquad (m = 0, 1, 2, \cdots) \tag{3}$$

Thus, the interval between two adjacent fringes is

$$S = x_2 - x_1 = \frac{\lambda}{2n_0\alpha} \tag{4}$$

If a flow field is measured with the interferometry, the relation of the fringes displacement $\varepsilon(y)$ to the refractive index $n(x,y,z)$ of the flow field is

$$\varepsilon(y) = \frac{2}{\lambda} \int_{-z_0}^{z} [n(x,y,z) - n_0] dz \tag{5}$$

Because a high speed camera is very expensive, in the system a new developed acousto-optical modulator and a rotating angle prism type of high speed scanning camera[4] are used to modulate CW He-Ne laser to provide a serial of laser pulses and to record the time series interferograms. Its operating principles are briefly described as follows:

When a ultrasonic wave travels through a crystal, the refractive index of the crystal will distribute as the sinusoidal function and construct a phase grating is produced in the crystal. If the incident angle of light beam is satisfied with the Bragg condition, there is only zero order and +1 order of diffraction. The deflective angle θ is[5]

$$\theta = \frac{\lambda}{V_s} f_s \tag{6}$$

where V_s is ultrasonic velocity, f_s is ultrasonic frequency and λ is incident light weve length. The ultrasonic wave is generated by a driver power and its frequency f_s is changed to accomplish periodical one dimension scanning of +1 order diffraction light. A series of modulation pulses are transmitted to the driver power to built the pulsed scanning light beam.

The high speed camera[4] contains a rotating right prism, used as a tilting mirror to reflect incident light at 90, and a internal drum on which a film is arranged. The rotating mechanism is able to provide the scanning from 0 to 360. The generator of serial-pulse signal and high speed camera are synchronized to correctly take the time series interferograms.

Experimental results and discussion

The experimental arrangement shown in Fig.1 is used to produce and

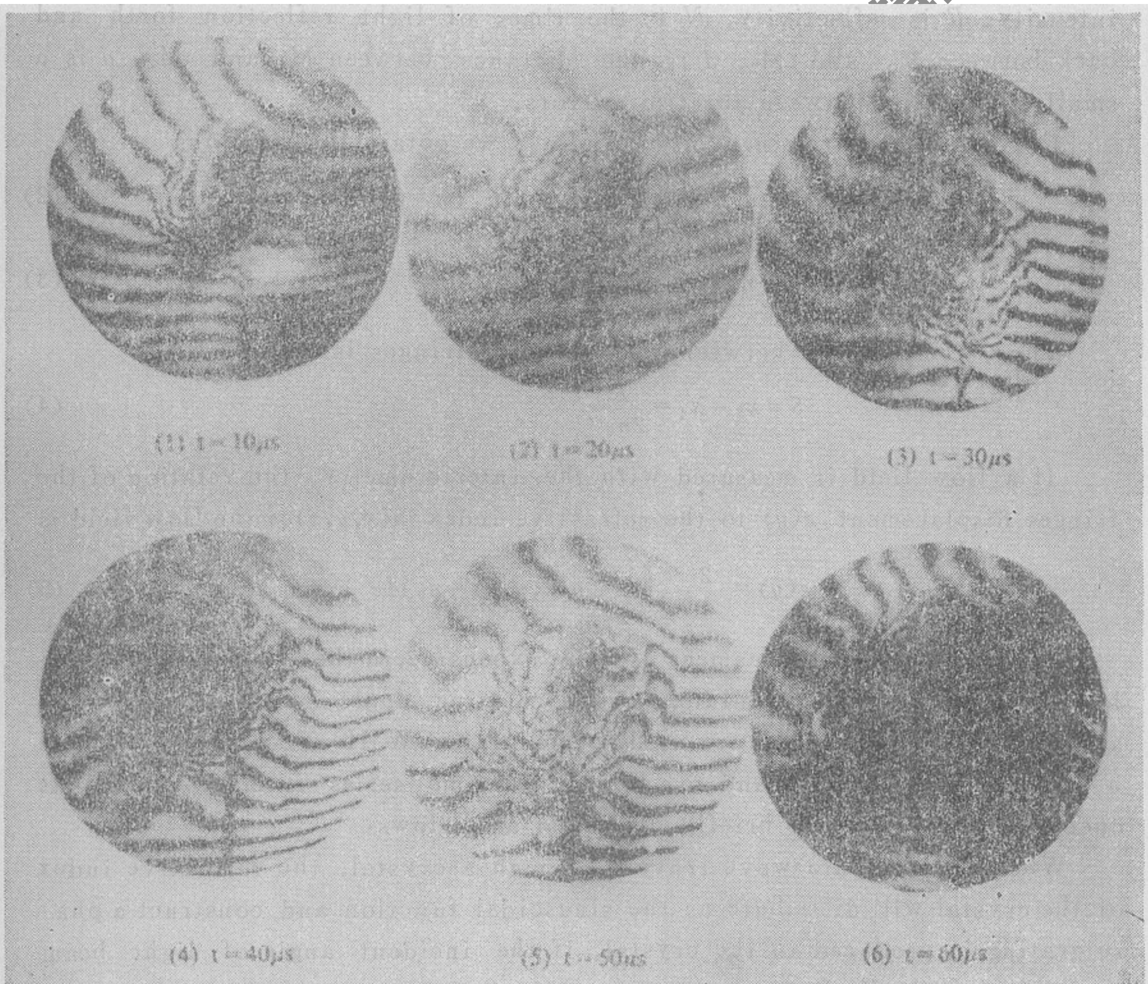

Fig. 2 Time series interferograms of explosive field of detonating powder

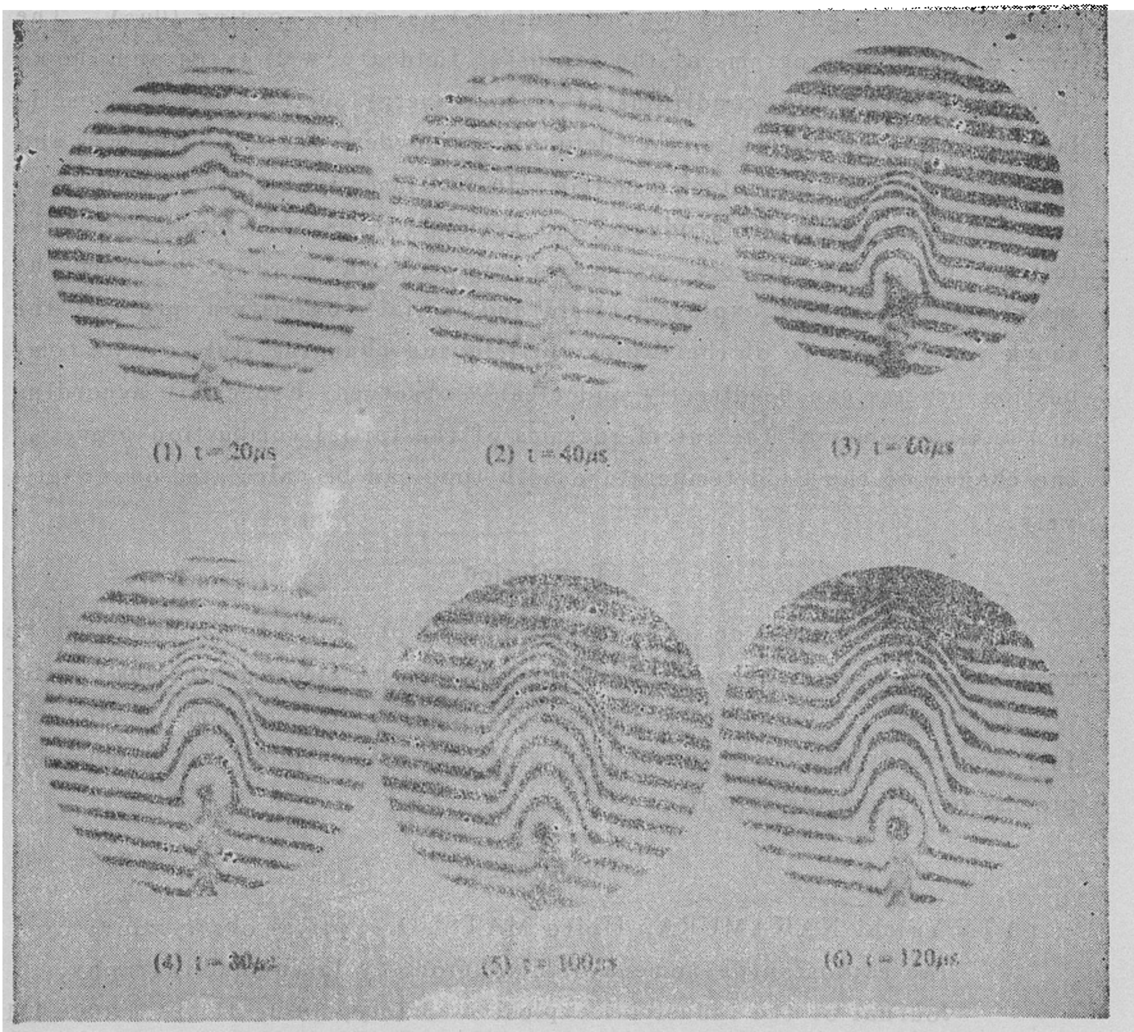

Fig. 3　Time series interferograms of initial combustion process of detonating powder

to visualize the explosive field and initial combustion process of detonating powder. In the experiment, we found that when the output energy of pulsed YAG laser is 50 mJ, no matter a Q-switch or free oscillation pulsed YAG laser is used to ignite the detonation powder, the explosive field can be produced. But when the output energy of the pulsed YAG laser is 30 mJ, the explosive field can not be generated by the Q-switch pulsed YAG laser, only the combustion process of the detonation powder can take place with the free oscillation puled YAG laser. The results show that there is a laser energy threshold to ignite the detonation powder. The phenomenon is a complex action of heat and shock and will be discussed in another paper.

In our experiments, a Q-switch pulsed laser (output energy 50mJ) is used to ignite the detonating powder, a pulsed He-Ne laser is used as the interferometric light source (pulsed width 0.1 μs, pulse spacing 10μs) . The time series interferograms of the explosive field are well taken and shown in Fig. 2. Under the conditions of output energy 30mJ of the free oscillation YAG laser to ignite the detonating powder, pulse width 1μs and spacing 20 μs of the interferometric He-Ne laser pulse, the combustion of detonating powder is produced and the time series interferograms of the initial combustion process are taken and shown in Fig. 3. From the interferograms of the explosive field and initial combustion process, the shock wave structure of the explosive field and changing state of the combustion process can be directly and clearly observed. Especially according to the time series of the interferograms of the initial combustion process, the change of the field temperature with time can be calculated quantitatively.

Conclusion

1. The method of time series interferometry presented in the paper can be used to visualize the explosive field and combustion field of detonating powder.

2. The serial time interferograms obtained in the experiment are usefull for studying the characteristics of explosive field and combustion process of detonating powder.

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