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STUDY OF HIGH SPEED INTERFERENCE PHOTOGRAPHY WITH TWO-DIMENSIONAL ACOUSTO-OPTICAL LATTICE DEFLECTION

by

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STUDY OF HIGH-SPEED INTERFERENCE PHOTOGRAPHY WITH  
TWO-DIMENSIONAL ACOUSTO-OPTICAL LATTICE DEFLECTION

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ABSTRACT: This paper presents the principle and method of high-speed interference photography by using the technique of two-dimensional acousto-optical lattice deflection. The light beam carrying the interferogram is deflected into a lattice of 10x10 light spots in a time series; the interferogram is recorded on a photographic negative. The CW laser is the light source; the exposure time can be adjusted between  $10^{-5}$  to approximately  $3 \times 10^{-6}$  s; the framing frequency was about  $10^5$  frames/s. This method was used to record interferograms of transient-state temperature fields in an experimental study of the principle.

Key words: acoustic-optical deflection technique, high-speed interference photography

## I. Introduction

The technique of acousto-optical deflection has been applied in information storage and optical communication. Especially in

the holographic interference technique, this acousto-optical lattice deflection technique has been used to deflect a reference beam to obtain multiframe interferograms [1]. However, in the application of this acousto-optical deflection technique the light beam as such does not carry the graphic information. To solve the problem of recording transient-state high-speed interference and to overcome the difficult problems of high cost and complex techniques of high-speed camera, unlikelihood of wide acceptance, the paper made an investigation to obtain a method of using the technique of two-dimensional acousto-optical lattice deflection for recording two-dimensional interferograms in a time series. In this method, the light beam carrying the interferogram is contracted to OD 6mm to approximately OD 8mm, which is then passed through an X-Y two-dimensional acousto-optical lattice deflection device to record one hundred frames of interferograms with 10x10 light spots in a time series on a fixed photographic negative. If a CW laser is used as the light source to generate the interferogram with a driving power supply to control the acousto-optical deflector, the exposure time for each frame is adjustable between  $10^{-5}$  to approximately  $10^{-6}$  s, the framing frequency was approximately  $10^5$  frames/s. If coordinated with a serially pulsed light source and by controlling a synchronous time-delay device the exposure time of each frame can be as little as  $10^{-9}$  s. In this way, the advantage of this high-speed interference photographic device is that the photographic negative does not move during the light exposure. At times other

than during the light exposure, the light beam is deflected rapidly, thus overcoming the problems of complicated mechanical rotation in high-speed photography, in addition to lowering the cost. This is a new method adaptable to transient-state recording of interferograms. By applying this method in the paper, an experimental setup under this principle was constructed. In addition, an experimental study of the principle was carried out on interferograms of transient-state temperature fields. As the results revealed, this method is feasible with certain potential applications.

## II. Principle of Two-dimensional Acousto-optical Deflection

When a supersonic wave forms a stationary or a moving wave in a medium, and the refractivity of the corresponding medium is varied according to a sine wave, thus forming a phase grating. If the light ray is incident at a certain angle, Bragg diffraction is produced.

From the diagram of the acousto-optical deflection principle and the vector diagram in Fig. 1, if the light beam is incident at an acousto-optical crystal at a Bragg angle, then the Bragg condition is satisfied [2]:

$$\theta_i - \theta_d - \theta_s = \frac{\lambda}{2V_s} - \frac{\lambda}{2V_s} f_s \quad (1)$$

In the equation,  $V_s$  is the speed of sound, and  $f_s$  is the supersonic frequency. From Eq. (1), when the incident angle and the diffraction angle are equal to each, then the deflection angle  $\theta$  is

$$\theta - \theta_i + \theta_d = 2\theta_s = \frac{\lambda}{V_s} f_s \quad (2)$$

If the supersonic frequency  $f_s$  is changed, then we have

$$\Delta\theta = \frac{\lambda}{V_s} \Delta f_s \quad (3)$$

then the deflection angle of the light beam can be changed, thus making it able to control the direction of light beam propagation.

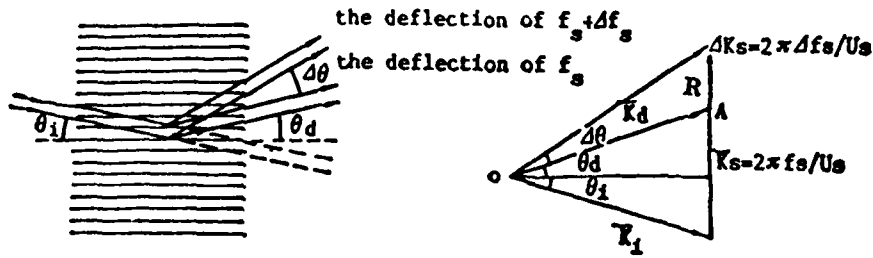


Fig. 1. Schematic drawing of acousto-optical deflection and its vector diagram

If a supersonic pulsed wave (with duration  $t_0$ , spacing  $T$ , and frequency in step variation) impinges on the acousto-optical crystal, then we have

$$\left. \begin{aligned} f_1 &= f_s \\ f_2 &= f_s + \Delta f_s \\ f_3 &= f_s + 2\Delta f_s \\ &\vdots \\ f_n &= f_s + (n-1)\Delta f_s \end{aligned} \right\} \quad (4)$$

When subjected to step-frequency pulsation, spot frequency deflection scanning takes place in the light beam, thus producing a light spot array with exposure time  $t_0$  and spacing  $T$ , as shown in Fig. 2.

The foregoing is the principle of one-dimensional acousto-optical lattice deflection. To achieve two-dimensional lattice deflection, another deflection device of Y-direction is needed; in addition, these two acousto-optical deflection devices of X-

and Y-directions deflect synchronously in order to achieve high-speed interference photography of two-dimensional lattice deflection.

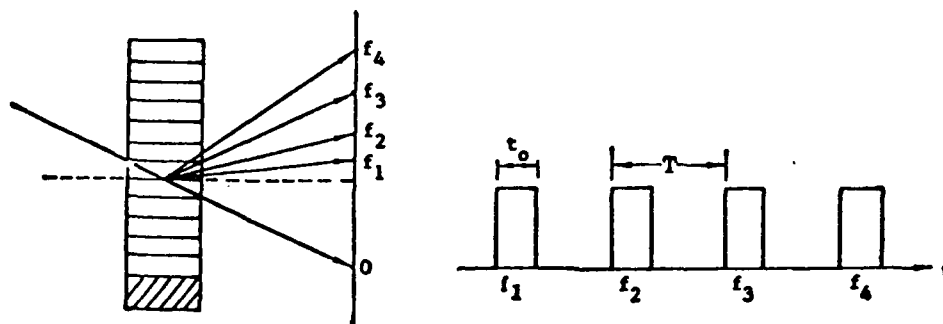


Fig. 2. Schematic diagram of lattice deflection

### III. Setup for Experimental Study of Principle

Fig. 3 shows a setup demonstrating the principle of high-speed interference photography with two-dimensional acousto-optical lattice deflection. In the figure,  $L_1$  and  $L_2$  are lenses for beam contraction;  $C_1$ ,  $C_2$ ,  $C_3$ , and  $C_4$  are cylindrical-surface lenses;  $A_1$  and  $A_2$  are the acousto-optical deflection crystals along the X- and Y-directions, respectively.

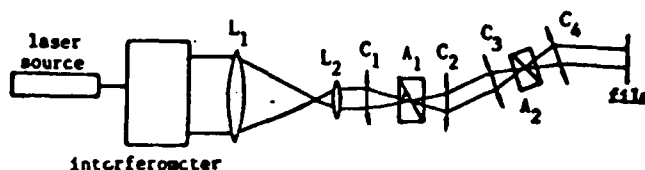


Fig. 3. Schematic diagram of high-speed interference photographic device with two-dimensional acousto-optical deflection

After beam contraction by passing through  $L_1$  and  $L_2$ , the interferogram (produced by the interference instrument) forms a

light beam with diameter OD 6mm or OD 8mm. From Eq. (2),

$$N = \frac{D}{V_s} \cdot \Delta f_s = \tau \cdot \Delta f_s, \quad (5)$$

$$\tau = \frac{D}{V_s}. \quad (6)$$

In the equations, N is the number of distinguishable spots; D is the light beam width;  $\tau$  is the transition time of the acoustic wave passing through the light beam zone. We can see that the bandwidth of the supersonic wave and the incident light beam width should be increased in order to upgrade the discriminability of the deflector. In this paper, the cylindrical-surface lenses C<sub>1</sub> and C<sub>2</sub> are employed to contract the light beam into thin light sheets in order to increase the width of the incident light. Moreover, another cylindrical-surface lens of the same parameter is used to restore the original field.

To obtain a deflection graph of variations with smaller anomaly, the optical system needs to be laboriously adjusted and tested, and high-quality acousto-optical crystals and optical elements need to be selected. In addition, the incident light beam is adjusted strictly at the Bragg angle to be incident at the crystal in order to achieve higher diffraction efficiency and discriminability.

To achieve synchronous two-dimensional lattice deflection of the incident light beam into the two acousto-optical deflectors along the X- and Y-direction, it is important to design the driving power source on the two acousto-optical crystals. Fig. 4 is a block diagram of the circuits. The working cycle signals

required to produce a ring-shaped oscillator, a timing working pulse signal (obtained by frequency division and shaping through a process) is inputted into the control gate circuit. The high-frequency oscillator along the X-direction outputs a signal from the control gate circuit to generate various high-frequency signals. After amplifying voltage and power, a high-frequency power amplifying signal is outputted. The working principle along the Y-direction in the concluding section is the same as along the X-direction in the concluding section. Upon adjusting the light path, interrupt the single-pass control circuit, thus exhibiting continuous repetitive scanning for observational convenience. When recording transient-state interferograms, single-pass scanning or electric triggering synchronization is necessary.

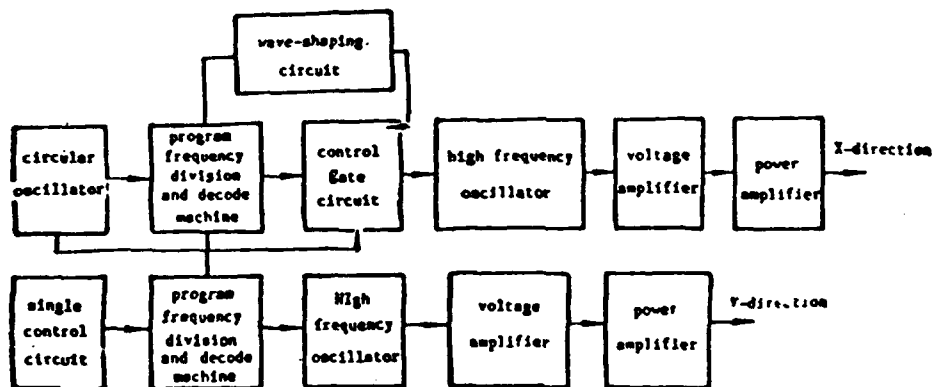


Fig. 4. Circuit diagram of two-dimensional acousto-optical lattice deflector

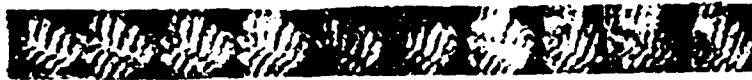


Fig. 5. Ten time-serial interferograms of temperature field recorded by a one-dimensional acousto-optical deflector

Fig. 3 shows the setup demonstrating the principle in the experiments. Two-dimensional lattice high-speed recording was carried out for the interferograms generated by an He-Ne laser and Mach interferometer with OD 100mm.  $A_1$  is the acousto-optical deflector in the X-direction;  $A_2$  is the acousto-optical deflector in the Y-direction. By adjusting the frequency of the supersonic wave, the exposure time of each frame was made adjustable between  $10^{-5}$  and approximately  $3 \times 10^{-6}$  s. The framing frequency was  $10^5$  frames/s. At a single pass, 100 frames of  $10 \times 10$  light spots each (showing lattice transient-state interferograms deflected in a time series) can be recorded. This technique is also used to record the interferograms generated by transient-state temperature fields. Fig. 5 shows the interferograms of ten frames of transient-state fields obtained by a one-dimensional acousto-optical deflector (in the X-direction). Fig. 6 shows 100 frames of time-series interferograms of transient-state temperature fields produced with a two-dimensional acousto-optical deflector.

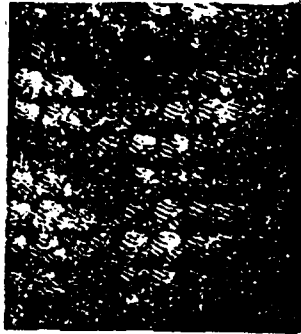


Fig. 6. 10x10 time-serial interferograms of temperature field recorded by a two-dimensional acousto-optical lattice deflection

#### IV. Conclusions

1. This kind of high-speed interference recording device by using two-dimensional acousto-optical lattice deflection can execute an ideally high-speed photographic state, while the optical field is relatively immobile during light exposure of the photographic negative; while there is relative motion between the photographic negative and the optical field other than the light exposure. In addition, the information recording capacity is high, and there is no interference due to noise of mechanical rotation in various kinds of mechanically rotated high-speed cameras. Moreover, the cost is low, thus making it especially adaptable in recording transient-state interferograms.

2. The dwell time of each spot in scanning the acousto-optical lattice is affected by the transition time, generally only of the order of microseconds. To achieve the order of nanoseconds, we can employ synchronous matching with a serial short-pulse laser so that each pulsation light source is

consistent with the dwell time of spot frequency, then the exposure time can be upgraded to the order of nanoseconds.

3. Since the interferograms pass through a light beam contraction system in addition to four cylindrical-surface lenses and two acousto-optical crystals, light spot quality is strongly affected by these optical elements. Since this paper serves the purpose only of investigating feasibility of the setup demonstrating the principle, no consideration was given to the quality and precision of the various optical elements in the experimental setup; therefore, the anomalous variation of the interferograms of the serial transient-state temperature fields obtained is fairly obvious. In addition, inhomogeneity of the intensities of the various light spots was caused by inaccurate adjustment and calibration of light paths.

4. As shown in the experimental results for the demonstration of the principle, this method of high-speed interference photography based on two-dimensional acousto-optical deflectors is feasible. If the quality of the optical elements, and the qualities of processing and the materials for the acousto-optical crystals can satisfy the design requirements, this method of high-speed interference photography has certain potential applications.

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