TWO-DIMENSIONAL ULTRASONIC SCANNING OF LIGHT

N. K. Maneshin, V. N. Parygin, and A. D. Sokurenko

Vestnik Moskovskogo Universiteta. Fizika, Vol. 30, No. 5,
pp. 574-578, 1975

UDC 621.372.029.7

Two-dimensional scanning of light by diffraction on a grating formed in α-HIO_3 by two acoustic waves propagating orthogonal to one another and having a common region of interaction is investigated. The maximum possible frequency deviation of each sound wave is calculated. The theoretical relations that are derived are tested experimentally. The intensity of the light deflected on the two coordinates was about 30% of the incident light.

The diffraction of light on ultrasonic waves is now one of the effective light-scanning methods, using Bragg diffraction (see [1]) to deflect a significant part of the light and obtain high resolution. Two-dimensional scanning can be accomplished by diffracting light on two acoustic waves propagating orthogonal to one another and having a common region of interaction with the light [2-5].

In this paper we determine the frequency band and, consequently, the resolution of such a scanning system.

In [5], an expression was derived for the intensity η_{11} of the light deflected on the two coordinates when the angle of incidence both of the light onto the region of interaction with the sound may differ from the Bragg angle for each of the controlling acoustic waves:

$$\eta_{11} = \eta_1 \eta_2. \tag{1}$$

Here η_1 and η_2 are the light-diffraction efficiencies for propagation of only a single ultrasonic wave in a photoelastic medium and are determined by

$$\eta_{i \atop (i=1,2)} = \frac{q_i^2}{q_i^2 + \gamma_i^2} \sin^2 \frac{l}{2} \sqrt{q_i^2 + \gamma_i^2}, \tag{2}$$

where $q_i \approx 2\pi\Delta n/n\lambda$ characterizes the change in the refractive index of the photoelastic medium due to the sound wave and γ_i is proportional to the deviation of the incidence angle of light (of wavelength λ) on the front of the sound wave from the Bragg angle $\varphi_{Br_i} = \frac{\lambda f_i}{2v_i}$:

$$\gamma_i = \frac{2\pi(\varphi_i - \varphi_{Br_i})}{\Lambda_i} = \frac{\pi(f_{0i} - f_i) f_i \lambda}{v_i^2}, \tag{3}$$

v_i and Λ_i are the velocity and wavelength of the sound, f_{0i} is the sound frequency for which the angle of incidence φ_i of the light coincides with the Bragg angle, and l is the width of the ultrasound beam along the propagation direction of the light. It follows from relations (1)-(3) that the intensity of the light deflected on the two coordinates varies on scanning. If the admissible intensity change is η_{11}, relations (1)-(3) can be used to determine the maximum possible retuning of the zoned frequency $\Delta f_{i_{min}} = D|f_{i_{max}} - f_{0i}|$, and thus to estimate the maximum attainable deflector resolution.

We shall compute the maximum frequency deviation of each sound wave on the assumption that the resolutions, response speed, and light-deflecting efficiencies are equal for both coordinates. In this case, $q_1 = q_2 = q$ and $\Delta f_1 = \Delta f_2 = \Delta f$. We shall regard a change by a

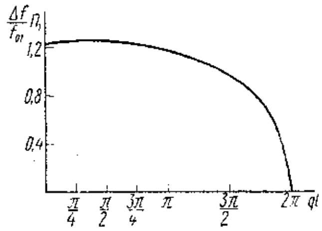

Fig. 1. Admissible frequency-retuning band vs. ultrasonic power.

factor of two (3 dB) in the intensity of the deflected light within the scanning region as acceptable. Under these assumptions, we have from (1)-(3)

$$\frac{\sin\psi_1}{\psi_1}\cdot\frac{\sin\psi_2}{\psi_2}=\frac{1}{\sqrt{2}}\,\frac{\sin^2\frac{ql}{2}}{\left(\frac{ql}{2}\right)^2}, \qquad (4)$$

where

$$\psi_i^2 = \frac{(ql)^2+(\gamma_i l)^2}{4}. \quad (i=1,2) \qquad (5)$$

Assuming $\gamma_i \simeq \frac{\pi\lambda}{v_i^2} f_{0i}\frac{\Delta f}{2}$, $(i=1,2)$ we obtain from (4) and (5)

$$\frac{\sin\psi_1}{\psi_1}\cdot\frac{\sin\sqrt{\xi^2\psi_1^2+\frac{1-\xi^2}{4}(ql)^2}}{\sqrt{\xi^2\psi_1^2+\frac{1-\xi^2}{4}(ql)^2}}=\frac{1}{\sqrt{2}}\,\frac{\sin^2\frac{ql}{2}}{\left(\frac{ql}{2}\right)^2}, \qquad (6)$$

where $\xi = \frac{\gamma_2}{\gamma_1} = \frac{f_{02}\cdot v_1^2}{f_{01}\cdot v_2^2}$.

Equation (6) can be used to calculate ψ_1 and hence also Δf for any acoustic-power value (any ql).

Figure 1 shows the widest possible frequency region band Δf as a function of acoustic power for the case $\xi = 1$. We see from the figure that at $0 < ql < \pi$, the bandwidth Δf changes insignificantly (within a 10% range). The value $ql = \pi$ corresponds to the ultrasonic power at which the intensity of the light deflected on the two coordinates reaches its maximum. At practically all ultrasonic-power values that are of practical interest, therefore, the permissible deviation Δf can be assumed equal to the value calculated from (6) with $ql = 0$:

$$\Delta f = \frac{1,24}{\Pi_1} f_{01}, \text{ where } \Pi_1 = \frac{\lambda l}{\Lambda_{01}^2} = \frac{\lambda l f_{01}^2}{v_1^2} \text{ — is the Bragg parameter.}$$

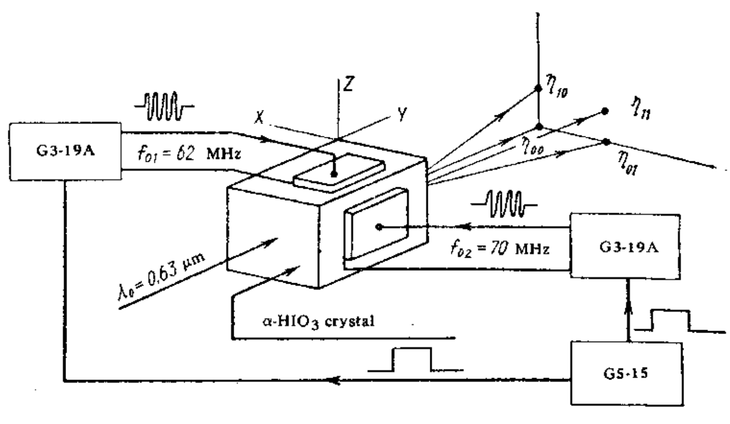

Fig. 2. Block diagram of system for study of two-dimensional light deflection.

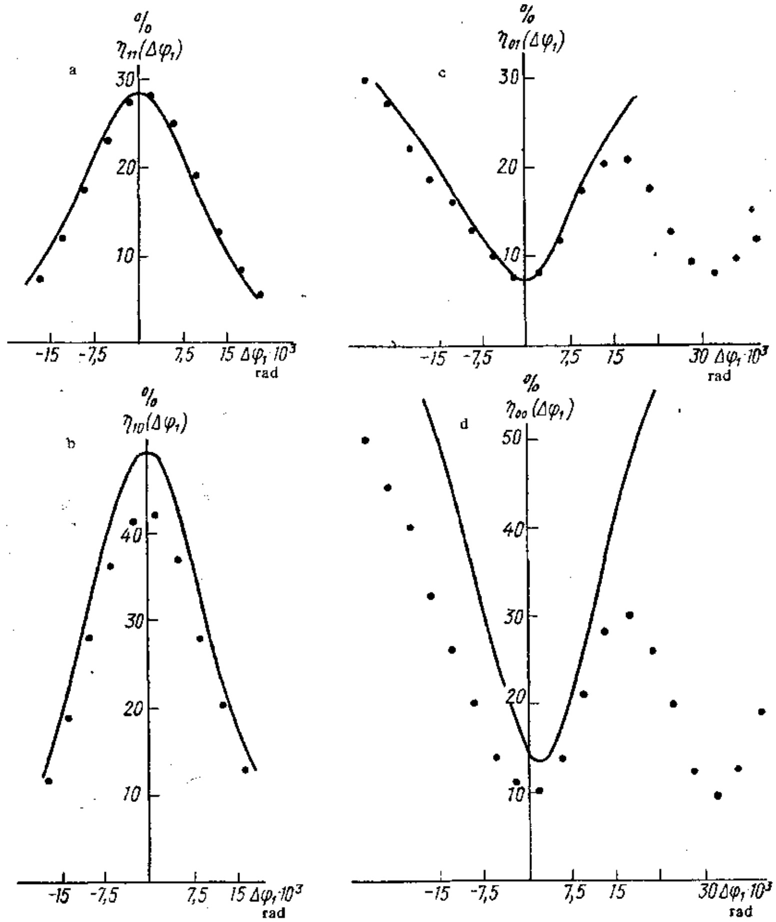

Fig. 3. Intensity of light in diffraction maxima vs. deviation of the angle of incidence of light on the ultrasound from the Bragg angle. a) $\eta_1(0) = 75$, $\eta_2 = 36\%$; b) $\eta_1(0) = 76$, $\eta_2 = 32\%$; c) $\eta_1(0) = 72$, $\eta_2 = 32\%$; d) $\eta_1(0) = 77$, $\eta_2 = 36\%$.

Using the equations given in [5], we can obtain simple expressions for the relative intensity of the light deflected on one of the coordinates when two acoustic waves propagate in the photoelastic medium:

$$\eta_{01} = (1 - \eta_1)\,\eta_2, \quad \eta_{10} = (1 - \eta_2)\,\eta_1 \tag{7}$$

and an expression for the intensity of the undeflected light:

$$\eta_{00} = (1 - \eta_1)(1 - \eta_2). \tag{8}$$

The working relationships obtained were checked in an experiment. It follows from expressions (1)-(3) that the manner in which η_{11} varies with Δf is determined by the decrease of η_1 with the detuning Δf_1. To follow the dependence of η_{11} on Δf_1, it is necessary to maintain a constant sound intensity as the frequency is varied. It is rather difficult to accomplish this in experiments owing to the frequency dependence of the equivalent electrical parameters of the piezoelectric transducers used to generate the sound [6].

The $\eta_{11}(\Delta f_1)$ dependence can be traced (see formula (3)) by varying the angle of incidence of the light onto the sound wave at a constant sound frequency, which is much simpler.

The block diagram of the system used to test the above relation appears in Fig. 2. Iodic acid, α-HIO_3, was used as the photoelastic material. Ultrasonic waves with frequencies of 62 and 70 MHz were excited along the Z and X axes, respectively, in the acid.

Ultrasound was generated with laminar Z-cut $LiNbO_3$ piezoelectric transducers, to which electric power was supplied from two G3-19A generators. Pure travelling sound waves were produced in the α-HIO_3 crystal by using the G3-19A generator in its pulsed operating mode. (The direction of the pulse was shorter than the time for the sound to transit the crystal.) Light at λ_0 = 0.63 µm, polarized along the Z axis, propagated nearly along the Y axis. The diffracted light was registered with a photomultiplier. The intensity of the sound in any diffraction maximum could be measured by moving the PM in the horizontal and vertical directions. The length of the piezoelectric transducers used in the experiment was such that the diffraction of the light on the sound wave propagating along the Z axis was nearly Bragg diffraction, in which the light is deflected into only one diffraction maximum. At $\eta_1 \simeq 80\%$, the intensity of the light deviated into the diffraction maximum symmetrical with respect to the zeroth maximum was 2%. For the sound wave propagating along the X axis, the imbalance between the +1 and -1 diffraction maxima was smaller (40 and 6%, respectively).

The plotted points in Fig. 3a represent the experimental values of the relative light intensity η_{11} as the incidence angle of the light moves away from the Bragg angle. The solid curve is the $\eta_{11}(\Delta\varphi_1)$, relation computed by the formula $\eta_{11}=\eta_2\eta_1(\Delta\varphi_1)$. The values of η_2 and $\eta_1(\Delta\varphi_1)$ were taken from a separate experiment.

Figures 3b and 3c show the intensity variation of the light deflected along one of the coordinates as a function of the angle $\Delta\varphi_1$ for propagation of two ultrasonic waves in the crystal simultaneously, and Fig. 3d the corresponding relation for the undeflected light (zeroth maximum). The plotted points are the experimental values on all figures.

The minor difference in absolute magnitude between the experimental values of η_{00} and η_{10} and those calculated from (7) and (8) result from the fact that the diffraction of the light on the sound wave propagating along the X axis was not pure Bragg diffraction. In fact, the multiplier $(1 - \eta_2)$ in (7) and (8) should have the form $(1 - \eta_2 - \delta)$, where δ is the sum of the intensities of the light deflected into the other diffraction maxima. The minimum of the experimental values of $\eta_{01}(\Delta\varphi_1)$ and $\eta_{00}(\Delta\varphi_1)$ at $\Delta\varphi_1 \simeq 30\cdot10^{-3}$ rad (see Fig. 3c,d) is explained by the fact that at a certain deviation of the incidence angle from the Bragg angle, efficient transfer of light begins again, but this time into the symmetrical, minus one diffraction maximum.

As the results in Fig. 3 provide adequate confirmation for expressions (1)-(8), which describe the intensity of the light in four diffraction maxima. Accordingly, the estimate for the maximum possible frequency deviation of the sound in each of the controlling sound waves can also be regarded as correct.

REFERENCES

1. E. I. Gordon, Appl. Opt., vol. 5, p. 1629, 1966.
2. N. Uchida and Y. Ohmachi, Japan J. Appl. Phys., vol. 9, p. 1, 1970.
3. J. T. La Macchia and G. A. Coquin, Proc. IEEE, vol. 59, p. 2, 1971.
4. A. K. Stolyarov et al., Kvantovaya elektronika, no. 1, 1971.
5. V. N. Parygin, Radiotekhnika i elektronika, vol. 19, p. 1, 1974.
6. N. K. Maneshin, E. R. Mustel', and V. N. Parygin, Radiotekhnika i elektronika, vol. 18, p. 7, 1973.

4 April 1974

Department of the Physics of Oscillations