PECULIARITIES OF PHOTOELASTIC EFFECT AND SOME IDEAS ON THEIR APPLICATION

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The peculiarities of acoustic -optic interaction in photoelastic media are analyzed in a context of their application for a solution of some radio electronic problems

1. GENERAL INFORMATION

At an excitation of an acoustic wave in a photoelastic medium there are dynamic modifications of an index refraction (density of a medium) occur. These modifications lead to the formation of a moving diffraction grating, whose step is equal to the acoustic wavelength, and the amplitude is proportional both to the amplitude of an acoustic wave, and to the photoelastic constant of the medium. At passage through such media, a number of parameters of an optical wave varies (modulates). This phenomenon is called as the effect of acoustic-optic interaction or photo-elastic effect. Acoustic-optic modulator is the device for realization of this effect. At the same time the title "acoustic light modulator" in the literature is often used. Acoustic-optic modulator consists of a photoelastic medium, to one edge of which an electro - acoustic transducer (EAT) is attached. EAT transforms an input electrical signal into an acoustic wave spreading in the photoelastic medium with a velocity, approximately, in 10^5 times less than the velocity of propagation of an electromagnetic wave.

Peculiarities of acoustic-optic interaction can be used for a solution of many problems of radio electronics.

The purpose of the present work is the analysis and evaluation of potential possibilities of photoelastic effect in a context of application of its peculiarities for signals processing.

2. PECULIARITIES OF PHOTOELASTIC EFFECT

Owing to acoustic-optic interaction an incident optical wave diffracts on dynamic modifications of the density of photoelastic media. Thus, the intensity, propagation direction and frequency of optical wave in diffraction order are defined by parameters of an electrical signal brought to terminals of the electro -acoustic transducer. Moreover, the response of the photodetector, disposed on a path of the diffraction order, lags from action on an electrical input on the time

$$\tau = x/\vartheta \quad , \qquad (1)$$

where x is a distance from the electro -acoustic transducer up to a point of the acoustic-optic interaction; ϑ is a velocity of propagation of elastic waves in the photoelastic medium.

Depending on a geometry and character of acoustic-optic interaction, diffractions of Raman-Nath and Bragg are distinguished. The basic external difference of Bragg diffraction from Raman-Nath diffraction consists of a unsymmetrical emerging of diffraction orders, with modification of the incidence angle θ_0 of a light beam in the aperture of the acoustic-optic modulator. Thus, the maximum of the light intensity in the diffraction order takes place if the light falls on the aperture of the acoustic-optic modulator at the Bragg angle, i.e. when $\theta_0=\pm\theta_B$. The Bragg angle is defined from the relation

$$\sin\theta_B = \lambda/(2\Lambda), \qquad (2)$$

where λ is the wave length of the incident light; Λ is the elastic wavelength in the photoelastic medium of the acoustic-optic modulator.

Acoustic-optic devices, using the Raman-Nath diffraction, have been extensively applied in systems of signal processing on frequencies up to 100 MHz. The Bragg diffraction is widely applied in acoustic-optic systems of signal processing working in the frequency region from a few tens of MHz up to units of GHz.

Application of acoustic-optic modulators, where the Bragg diffraction is used, allows to raise some technical characteristics of acoustic-optic devices, for example: the central frequency of a pass band; light intensity in a diffractional order etc.

It is established, that the intensity I_1 of a deviating light in the Bragg diffraction mode is directly proportional to the square of input voltage U_0 [1]:

$$I_1 = BU_0^2 \qquad (2)$$

where B is the constant factor. Accordingly, the output voltage of the photodetector with the definite precision repeats the law of a modification of amplitude of the input voltage.

At $\theta_0=\pm\theta_B$, with increase of the frequency of an acoustic wave, diffractional effects of higher orders disappear and only light beams of zero and first orders are predominating. The diffractional order spread under the angle θ_d, defined from the relation

$$\sin\theta_d + \sin\theta_0 = \lambda/\Lambda \qquad (4)$$

Assuming, that the incidence angle θ_0 of the light beam on a surface of the photo-elastic medium is constant, i.e. $\theta_0=\pm\theta_B=const$, where θ_{B0} is the Bragg angle on the central frequency F_0 of the input action, from the joint analysis (2) and (4) it is possible to receive the following expression for the diffraction angle θ_d at the Bragg condition:

$$\sin\theta_d + \sin\theta_0 = \lambda/\Lambda , \qquad (5)$$

where F is the frequency of the elastic wave in the photoelastic medium.

The equation (5) indicates that the angle of deflection θ_d is variable versus the frequency F of elastic waves in a photo-elastic medium, and therefore also versus the frequency of the input electrical signal. From (5) for small modifications of the diffraction angle $\Delta\theta_d$ (where $\sin\Delta\theta_0 \approx \Delta\theta_B$.), it is possible to receive the following expression:

$$\Delta\theta_d = 0.5\lambda\cdot\Delta F/\vartheta \ , \qquad (6)$$

where $\Delta F = F - F_0$.

According to (6), in the Bragg condition a modification of an angle of diffraction is in the rectilinear dependence on a frequency modification of an input action.

After acoustic-optic interaction the frequency ω_d of the light beam in a diffractional order is shifted due to Dopler effect on the magnitude $\Omega = 2\pi F$ and is defined as:

$$\omega_d = \omega \pm \Omega \ , \qquad (7)$$

where ω is the angular frequency of light in the photo-elastic medium.

3. APPLICATION OF PECULIARITIES OF PHOTOELASTIC EFFECT

The analysis of relations (1) and (3) allows то postulate, that a signal given on the electrical input of the acoustic-optic modulator and extracted through the photo-elastic connection on a distance x from the electro-acoustic transducer receives the temporal delay τ defined by the relation (1). In other words, at feed of the following amplitude - modulated signal to terminals of the electro-acoustic transducer

$$U_1(t) = U_0[1 + M\cdot s(t)]\cos\Omega t \qquad (8)$$

where U_0 is the amplitude of the no modulated carrier; M is the index of the amplitude modulation; $s(t)$ is the modulating process on the output of the photodetector, we obtain:

$$U_2(t) = c\cdot s(t - x/\vartheta) \qquad (8)$$

where C is the constant factor. Thus, the indicated delay linearly depends on x and can be changed in large limits. For example, if we use TeO_2 as the photo-elastic medium, where the velocity of the slow shift wave is equal to 617m/s, then at x=2cm we receive τ=32mcs (TeO_2 allows to receive the temporal aperture ≈80mcs). Therefore, the smooth modification of x from 0 up to 2 cm will be accompanied by a smooth control of the delay time of the output signal from 0 up to 32 mcs accordingly. The modification of the indicated distance can be carried out by mechanical, electromechanical and electronic [2,3] methods.

The adduced numerical example shows, that the low acoustic velocity is favorable at construction of acoustic-optic delay lines. Let's mark, that in crystals of halogens of mercury (in particular, Hg_2Br_2 and Hg_2Cl_2) the velocity of a sound is 2 times less, than in TeO_2 [4].

According to relation (6), the modification of the frequency of input action is accompanied by a linear modification of a diffraction angle in space, as a result each direction of a light diffraction (in the plane xz) corresponds to definite frequency of input action (fig.1). This peculiarity of the Bragg diffraction can be used for detection of frequency - modulated signals [5], the spectral analysis of broadband signals. The work of the panoramic receiver [6], receiver of line frequency -modulated signals [7] is founded on this principle. This peculiarity can be used, also, for reading of an information from the storage device in acoustic-optic transformators of a temporal scale of signals [8]. Low acoustic velocity is favorable in these devices also on cause, that allows to receive large angles of a deviation and secures high resolution on the frequency. At the same time it does not allow to receive large velocity of a deviation.

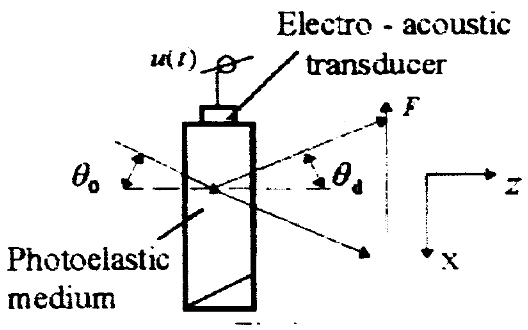

Fig.1

Caused by Dopler effect, the shift of frequency of a light wave in a diffractional order can be used for restoring of the radio-frequency signal operating on the input of the acoustic-optic modulator, by optical heterodyne of the diffracted light beam by a part of the incident or undiffracted light (appearing in a role of the local heterodyne) [9,10]. In this case, if an amplitude-modulated signal (8) is brought to terminals of electro -acoustic transducer, we have on the output of the photodetector:

$$u'_2(t) = c' U_0\left[1 + M\cdot s(t - x/\vartheta)\right]\cdot\cos\Omega(t - x/\vartheta) \ . \quad (10)$$

where C' is constant factor.

We mark, that the heterodyne method of registration of an optical signal allows to increase sensitivity of a photoreception device on 3-4 orders in comparison with the direct detection and approaches this sensitivity to the quantum limit.

CONCLUSION

The above mentioned examples on application of peculiarities of acoustic-optic effect show, that development of effective electro -acoustic transducers and photo -elastic media with high refraction factor will allow to synthesize simple devices solving highly difficult problems. We mark, that acoustic-optic modulator have been already developed, requiring only some tens mW on the electrical input for security of effective acoustic-optic interaction. The important virtue of acoustic-optic methods of signals processing is that the device used for a solution of one task can be easily adapted for solution of other. For example, devices of a delay of signals can be used also, as the acoustic-optical frequency detector, by placing of the diaphragm with the cuneiform orifice on a path of the diffractional order.

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FOTOELASTİK EFFEKTİN XASSƏLƏRİ VƏ ONLARIN TƏTBİQİ HAQQINDA BİR SIRA TƏKLİFLƏR

Bir sıra radioelektronika məsələlərinin həlli kontekstində, fotoelastik mühitlərdə akustooptik qarşılıqlı təsirin xüsusiyyətlərinin analizi verilir.

А.Р. Гасанов

ОСОБЕННОСТИ ФОТОУПРУГОГО ЭФФЕКТА И НЕКОТОРЫЕ ПРЕДЛОЖЕНИЯ ПО ИХ ПРИМЕНЕНИЮ

Анализируются особенности акустооптического взаимодействия в фотоупругих средах, в контексте их применимости для решения некоторых радиоэлектронных задач.

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