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Two-element Light Modulators

Two new systems of light modulators presented in the paper comprise two-element modulators, allowing the modulation at simultaneous actions of current and voltage. It seems that the modulators of this type can be used in control of electronic power.

The new concept of light modulation is based on electrooptical and magnetooptical phenomena applied simultaneously. A scheme of modulator circuit is shown in Fig. 1. It

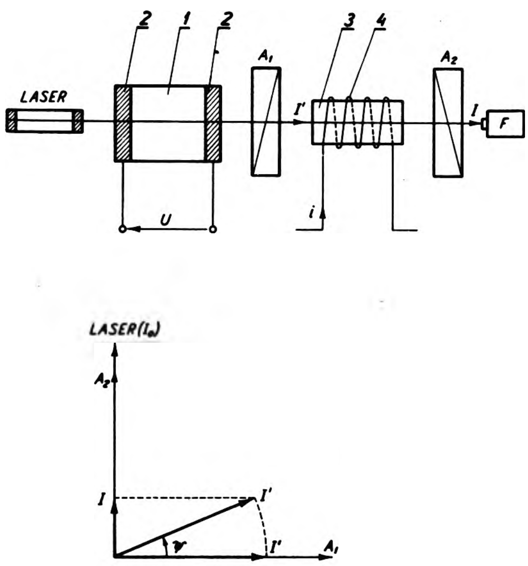

Fig. 1

consists of Pockels cell — *1*, *2*, and Faraday cell *3*, placed on the path of a laser radiation beam. Analyzer A_1 is situated between electrooptical and magnetooptical crystals. Polarization plane of the analyzer A_1 is perpendicular to the direction of laser polarizing beam. Another analyzer A_2 crossed with the analyzer A_1 is placed behind the magnetooptical crystal.

The intensity of light coming from this two-element modulator is measured with a photodetector F. A light beam can reach the photodetector only when the voltage U is applied to transparent electrodes *2* of Pockels cell and the current i flows through the winding *4* of Faraday cell.

It seems that the said two-element modulator can be used for the control of electric power in high voltage systems, because of a strong non-linearity, occuring at constant power, for low voltages and low currents, and associated with the character of electro- and magnetooptical phenomena. This non-linearity can be reduced considerably, by using the modulator shown in Fig. 2. This modulator is

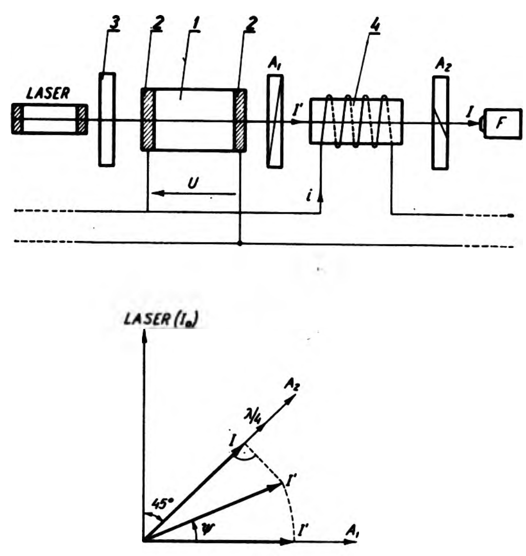

Fig. 2

equipped additionally with a quarter-wave plate *3*, placed between the electrooptical crystal and the laser. Optical axis of the quarter-wave plate and the polarization plane of the laser beam makes the angle amounting to 45°. Moreover, the intersection angle of the analyzer A_2, and the analyzer A_1 is now not 90° but 45°. By introduction of the quarter-wave plate into the modulator circuit and by placing the analyzer A at an angle 45° Pockels

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and Faraday cells work within the linear sections of characteristics.

In absence of signals U and i the photodetector in Fig. 2 records a constant intensity of the light beam. The receiver in the modulator is sensitive to each of the introduced values. From technological point of view it is possible to construct a receiver which would record only simultaneous interaction of the voltage U and the current i. At constant power the modulator described (Fig. 2) is characterized by linearity within a wide range of changes in voltage and current.

When a voltage is applied to the crystal and the light beam runs in the direction of the z-axis of the crystal, and the angle between the axes x, y and the polarization plane of the light is 45°, two linearly polarized beams run in it. Their phases are shifted with respect to each other at angle δ, which equals [1]

$$\delta = \frac{2\pi}{\lambda} n_0^3 r_{63} U, \tag{1}$$

where λ – length of the radiation wave,
n_0 – coefficient of refraction for an ordinary ray,
r_{63} – electrooptical coefficient.

If polarization surfaces of the analyzer and the light falling into the electrooptical crystal (Fig. 1) are perpendicular, then the intensity of light behind this analyzer is equal to

$$I' = I_0 \sin^2 \frac{\delta}{2}, \tag{2}$$

when I_0 is the intensity of light coming into the photodetector when analyzers A_1 and A_2 are parallel and $U = 0$, $i = 0$. I' is the intensity of light coming into the Faraday's cell.

In the crystal to which alternating voltage has been applied

$$U = U_0 \sin\omega t, \tag{3}$$

where U_0 – the amplitude of the voltage, ω – the frequency of this voltage.

Phase δ changes in time according to the formula

$$\delta = \delta_0 \sin\omega t, \tag{4}$$

where

$$\delta_0 = \frac{2\pi}{\lambda} n_0^3 r_{63} U_0. \tag{5}$$

Therefore [1]

$$I' = I_0 \sin^2 \left(\frac{\delta_0}{2} \sin\omega t\right). \tag{6}$$

When the modulator works within the linear section of the characteristic (Fig. 2) – [1]

$$I' = \frac{I_0}{2} \sin(\delta_0 \sin\omega t) + \frac{I_0}{2}. \tag{7}$$

After passing through the magnetooptical crystal of l length the plane of the beam polarized linearly is turned at angle Ψ,

$$\Psi = VHl, \tag{8}$$

where V – constant of Verdet, H – intensity of the magnetic field in the crystal, l – length of the optical way in the magnetooptical crystal.

The intensity of the magnetic field H is the linear function of the current in Faraday cell

$$H = ci \tag{9}$$

thus

$$\Psi = cVli. \tag{10}$$

When the current is a sinusoidal variable, according to the formula

$$i = i_0 \sin\Omega t$$

then the turn of the angle

$$\Psi = \Psi_0 \sin\Omega t, \tag{11}$$

where

$$\Psi_0 = cVli_0. \tag{12}$$

If the two analyzers A_1 and A_2 (Fig. 1) are crossed perpendicularly, then the intensity of light leaving the modulator is given by the formula

$$I = I' \sin^2 \Psi, \tag{13}$$

where I is the intensity of light coming into the photodetector for $U \neq 0$ and $i \neq 0$.

Formulae (11) and (13) give

$$I = I' \sin^2(\Psi_0 \sin\Omega t). \tag{14}$$

When the modulator works within the linear section of the characteristic (Fig. 2), then [1]

$$I = \frac{I'}{2} + \frac{I'}{2} \sin(2\Psi_0 \sin\Omega t). \tag{15}$$

The intensity of light leaving the modulator (Fig. 1) (when Pockels cell and Faraday cell work simultaneously) obtained from (6) and (14) is given by the formula

$$I = I_0 \sin^2 \left[\frac{\delta_0}{2} \sin(\omega t + \varphi)\right] \times$$
$$\times [\sin^2(\Psi_0 \sin \Omega t)]. \quad (16)$$

For the linear two-element modulator (Fig. 2) the analogical formula is obtained from (7) and (15)

$$I = \frac{I_0}{4}\left[1 + \sin\left(\delta_0 \sin(\omega t + \varphi)\right)\right] \times$$
$$\times [1 + \sin(2\Psi_0 \sin \Omega t)]. \quad (17)$$

If the two-element modulator be used in networks of alternating current, then it should be considered that

$$\omega = \Omega,$$

and

$$\omega t = \Omega t + \varphi,$$

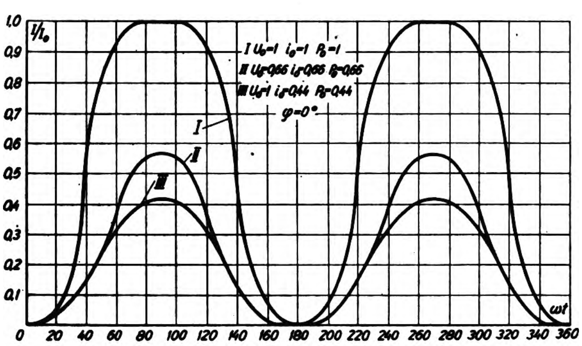

Fig. 3

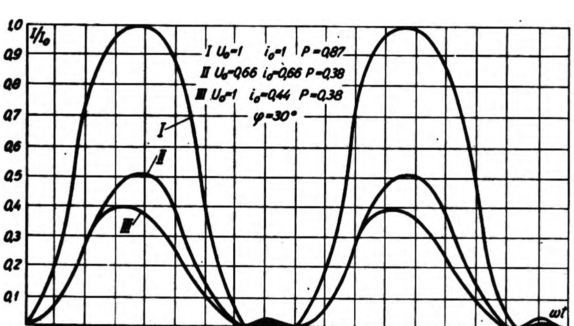

Fig. 4

where φ is an angle of shift of phase between the current and the voltage.

For example, curves $I/I_0 = f(\omega t)$ for $\varphi = 0°$ and $\varphi = 30°$ have been drawn according to the formula (16).

These curves are presented in Figs 3 and 4. Curves *I*, *II*, *III* are given for different values of voltage U_0 and current i_0.

Fig. 3 and Fig. 4 show that relation between the ratio I/I_0 and the active power is not univocal.

That is why modulator shown in Fig. 1 can be used for control of active power in a power line, with $U = \text{const}$ and $\cos\varphi = \text{const}$ or $i = \text{const}$ and $\cos\varphi = \text{const}$.

Similarly, for modulator shown in the Fig. 2 the curves $I/I_0 = f(\omega t)$ for $\varphi = 0°$ and $\varphi = 30°$ have been according to the formula (17) (Fig. 5 and Fig. 6). The shortcoming of this modu-

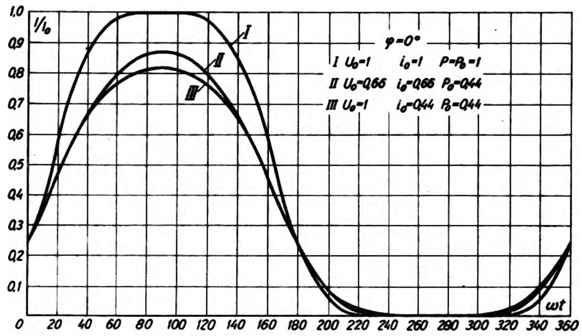

Fig. 5

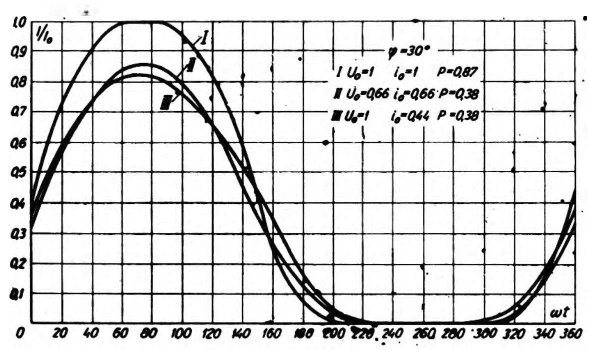

Fig. 6

lator is that for $\cos\varphi = 0$, $I/I_0 \neq 0$. Therefore for $\cos\varphi = 0$ the signal must be compensated. The compensation (autocompensation) can be achieved in the feed back block of the electronic system. The modulator shown in Fig. 2 can be used for the control of active power in a power line with $U = \text{const}$ and $\cos\varphi = \text{const}$ or $i = \text{const}$ and $\varphi = \text{const}$.

Двухэлементные модуляторы света

В работе описаны две новые системы модуляторов света. Это — двухэлементные модуляторы света, в которых модуляция возможна при одновременном действии двух величин — тока и напряжения. Представляется, что модуляторы этого типа могут применяться для контролирования электрической мощности.

Reference

[1] MUSTIEL E. R., PARYGIN W. N., *Metody modulacji światła*, PWN, Warszawa 1974.

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