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Electrooptical beam splitter for optical investigations*

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The paper presents the operation principle, construction of electrooptical laser beam splitter and examples of its application. This beam splitter due to its properties is competitive to widely used beam splitters, such as thin-film coated mirrors, beam splitters with the frustrated total internal reflection and others, as it allows us to obtain the energetic ratio of divided beams in the range $(0-\infty)$ with fine, remote electronic control, keeping the spatial position of beams. Applicabilities of this beam splitter are shown in a classic interferometer used for the investigation of elements having various transmission coefficients and in a set-up used for testing the objects by means of holographic methods.

1. Introduction

In practice for beam splitting of plane polarized laser beams the following elements are used: thin film metallic or dielectric mirrors having various transmission, beam splitter cubes, pellicle splitters, system composed of crystal polarizers, half-wave plates and others [1].

In classical interferometry of holographic investigations most of the methods of beam splitting of laser light widely used in practice, are not optimal because they do not satisfy the following conditions:

— In most cases the ratio of beam splitting should be controlled, and a wide range of beam splitting ratio is required, moreover, the total power of laser beam should be completely utilized.

— CW laser beams are usually filtered, thus in the beam-splitting the high spatial stability is required.

— Holographic investigations require high mechanical stability of optical elements to assure a constant phase relations of interfering beams during the hologram exposure.

— An automatic, remote control of beam splitter is sometimes required.

All the above mentioned conditions are met in the presented method of the beam splitting, in which an electrooptical modulator is applied. The operation principle of such a beam splitter has been verified in a classical interferometer. Experimental verification of its parameters confirms the usefulness of the proposed method in other fields of optical investigations.

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2. Operation principle of beam splitter

The Pockels-cell (*PC*) modulator with longitudinal Pockels-effect is the basic element of this beam splitter. The remaining elements of beam splitter are Glan polarizer (*GP*) and half-wave plate $P_{\lambda/2}$.

The investigations were carried out in the experimental set-up shown in Fig. 1.

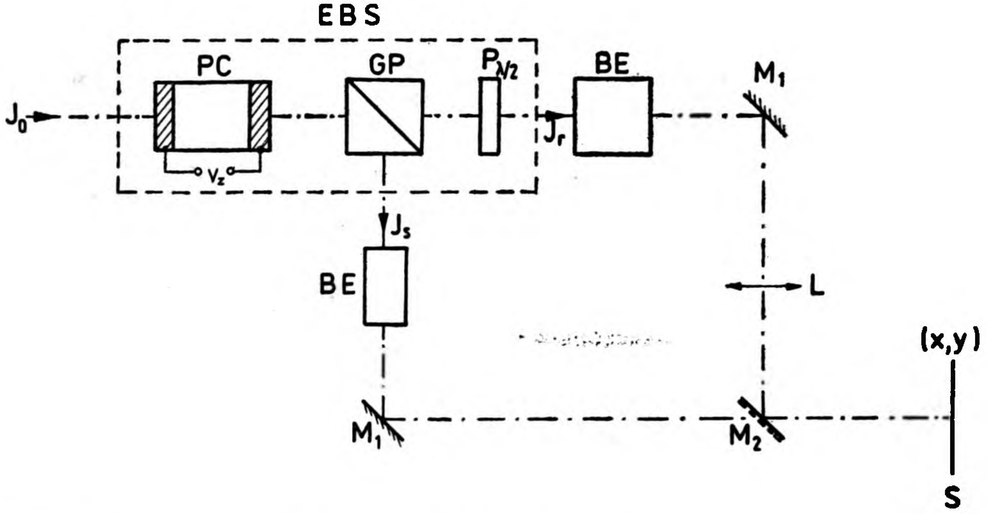

Fig. 1. Block-scheme of the interferometer with electrooptical beam splitter (*EBS*). J_0, J_s, J_r – intensities of laser beams, *PC* – Pockels-cell, *GP* – Glan prism polarizer, $P_{\lambda/2}$ – half-wave plate retarder, *BE* – beam expander with LPSF, M_1 – fully reflecting mirror, M_2 – transmission mirror, *L* – lens, *S* – screen (photosensitive material)

The light intensity distribution of interfering plane and spherical waves were recorded (at various values of interelectrode control voltage V_z) on the photosensitive material placed in the *S*-plane. The light intensity distribution observed in *S*-plane is described by the expression [1]

$$J = J_r + J_s + 2\sqrt{J_r J_s}\cos\varphi \tag{1}$$

where φ is the phase difference of interfering waves, the particular components of the above expression are the function of the spatial coordinates (x, y).

The expression (1) may be rewritten in the form

$$J = (J_r + J_s)\left(1 + \frac{2\sqrt{R}}{R+1}\cos\varphi\right), \tag{2}$$

$$R = J_r / J_s.$$

Visibility of interference distribution is

$$W = \frac{J_{\max}-J_{\min}}{J_{\max}+J_{\min}} \tag{3}$$

where in view of (1) $J_{\max}$, $J_{\min}$ denoting extreme values can be expressed as

$$J_{\substack{\max\\ \min}} = J_r+J_s \pm 2\sqrt{J_r J_s}\,, \tag{4}$$

then

$$W = \frac{2\sqrt{R}}{R+1}. \tag{5}$$

Based on the simple analysis of the light modulation we can write [2]:

$$\frac{J_s}{J_0} = \cos^2 \frac{V_2}{V_{\lambda/2}}\frac{\pi}{2},$$

and

$$\frac{J_r}{J_0} = 1-\frac{J_s}{J_0} = \sin^2 \frac{V_z}{V_{\lambda/2}}\frac{\pi}{2}, \tag{6}$$

then

$$R = \tan^2 \frac{V_z}{V_{\lambda/2}}\frac{\pi}{2}.$$

If we neglect transmission losses of the plate $P_{\lambda/2}$ and assume that the elements *BE* forming the laser beam are identical, we may write the visibility, given by (5), in the form

$$W = \sin \frac{V_z \pi}{V_{\lambda/2}} \tag{7}$$

where $V_{\lambda/2}$ is half-wave voltage defined by

$$V_{\lambda/2} = \frac{\lambda}{2n_0^3 r_{63}}, \tag{8}$$

and λ — laser light wavelength,
n_0 — crystal refractive index,
r_{63} — electrooptical coefficient.

Amplitude transmittance T_A of the exposed and processed photosensitive material can be expressed in the linear approximation as

$$T_A = a-bE \tag{9}$$

where: a, b determine the type of material and its processing,
E – the exposure proportional to the product of the light intensity and the exposure time τ.

Such a characteristic is shown in Fig. 2 for the typical photosenstive material.

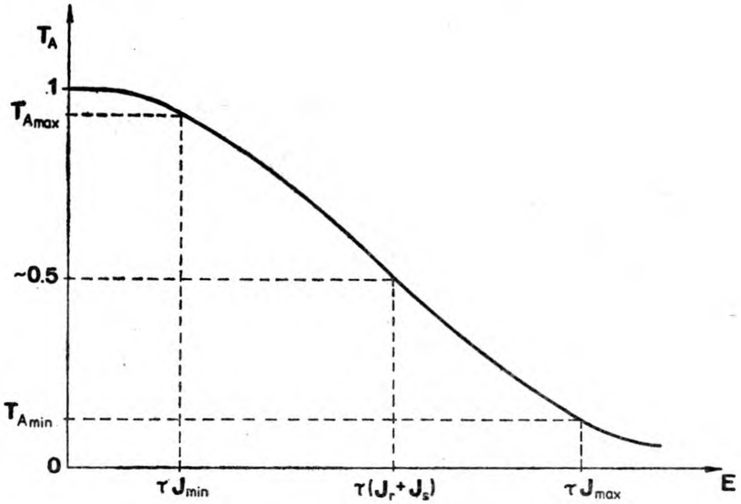

Fig. 2. Characteristic $T_A = f(E)$ for typical silver halide photographic material. T_A – amplitude transmittance, E – exposure

Taking into account the amplitude modulation of recording material we can write

$$\frac{J_{\max}}{J_{\min}} = \frac{T_{A\min}}{T_{A\max}} = \sqrt{\frac{t_{\min}}{t_{\max}}} \tag{10}$$

where $t_{\min}$ and $t_{\max}$ denote extreme transmission of the exposed material.

In view of (10) the Equation (3) can be written

$$W = \left|\frac{\sqrt{\frac{t_{\min}}{t_{\max}}} - 1}{\sqrt{\frac{t_{\min}}{t_{\max}}} + 1}\right|. \tag{11}$$

Let us formulate the conclusions resulting from Fig. 3:

– the energetic ratio $R = 1$ is determined by $\lambda/4$ – voltage which is denoted by $V_{\lambda/4}\,[V_{\lambda/4} = 0.5 \times V_{\lambda/2} \rightarrow (8)]$,

– the arbitrary beam splitting ratio from the range $0 < R < \infty$ requires that the voltage V_z belongs to the interval $0 < V_z < V_{\lambda/2}$,

– the maximum level of the interference distribution visibility $W = 1$ can be obtained when $J_r = J_s$ $(V_z = V_{\lambda/4})$.

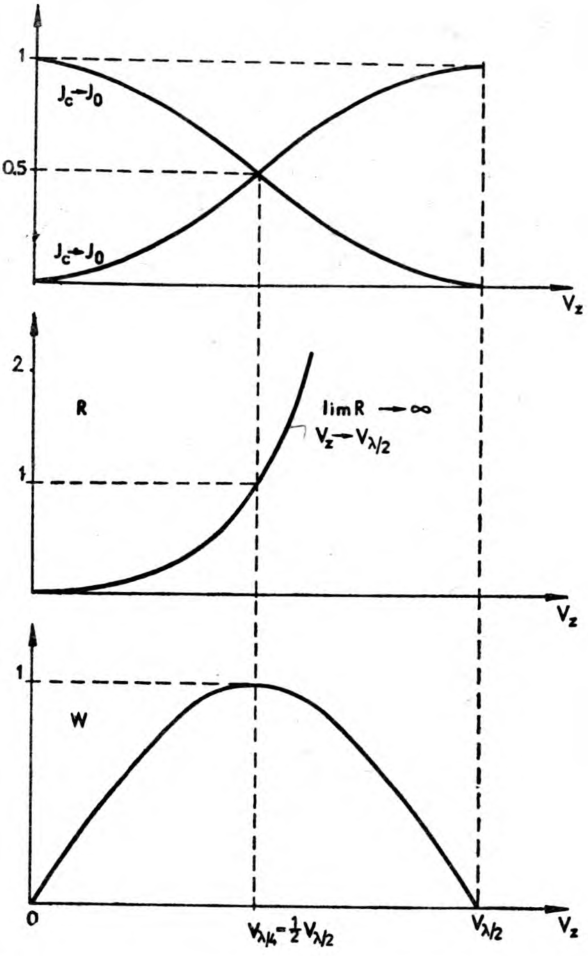

Fig. 3. Theoretical dependences of beam intensities ratio R and visibility W as a function of the control voltage V_z

3. Experimental results

Experiments were carried out using a high-stability stand with typical elements of the ZHB holographic system, shown in Fig. 4. As a light source He-Ne laser having 10 mW linear polarized beam was used.

The interference pattern shown in Fig. 5 was recorded on the 8E75-AG Holotest sensitive material at various voltages V_z^i, $i = 1$–6. The transmission

t of the selected single fringe, denoted in Fig. 5 by an asterisk, was determined for a few values of the voltage V_z^i by the densitometric examination.

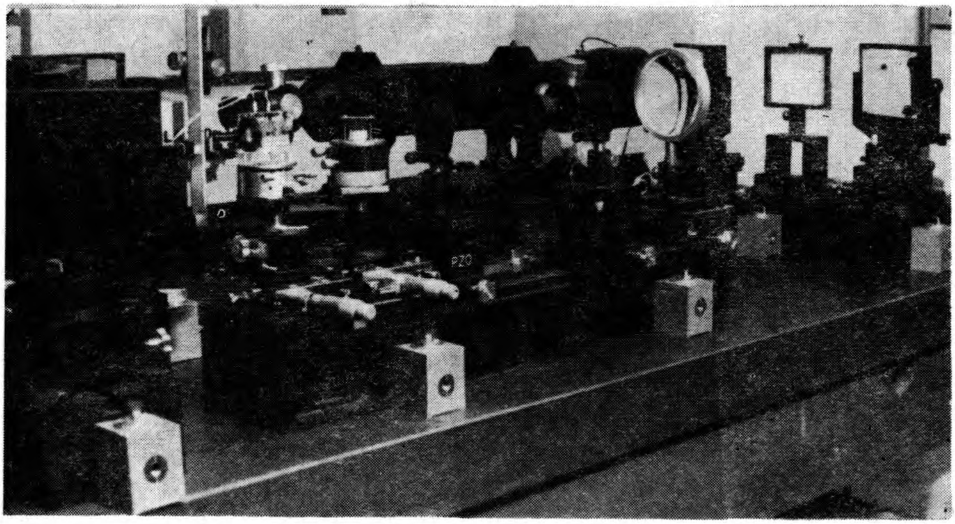

Fig. 4. General view of interferometer shown in Fig. 1

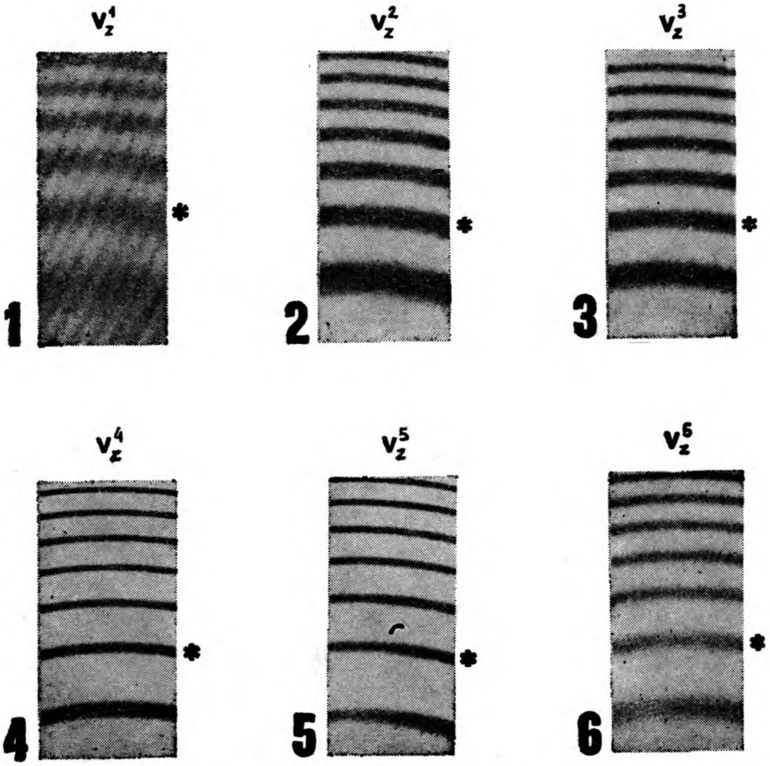

Fig. 5. Interference patterns corresponding to the various control voltages V_z

For the KDDP – crystal Pockels cell, in our experiment, the $\lambda/2$ – voltage was equal to $V_{\lambda/2} \approx 3.8$ kV. Interference patterns, shown in Fig. 5, correspond to the following control voltages:

$$V_z^1 = 0,\ V_z^4 = V_{\lambda/4},\ V_z^6 = V_{\lambda/2},$$

and to other voltages lying in the ranges:

$$0 < V_z^2 < V_z^3 < V_{\lambda/4},\ V_{\lambda/4} < V_z^5 < V_{\lambda/2}.$$

The visibility of interference fringes at the voltages V_z^i $(i = 1\text{–}4)$ are shown in Fig. 6.

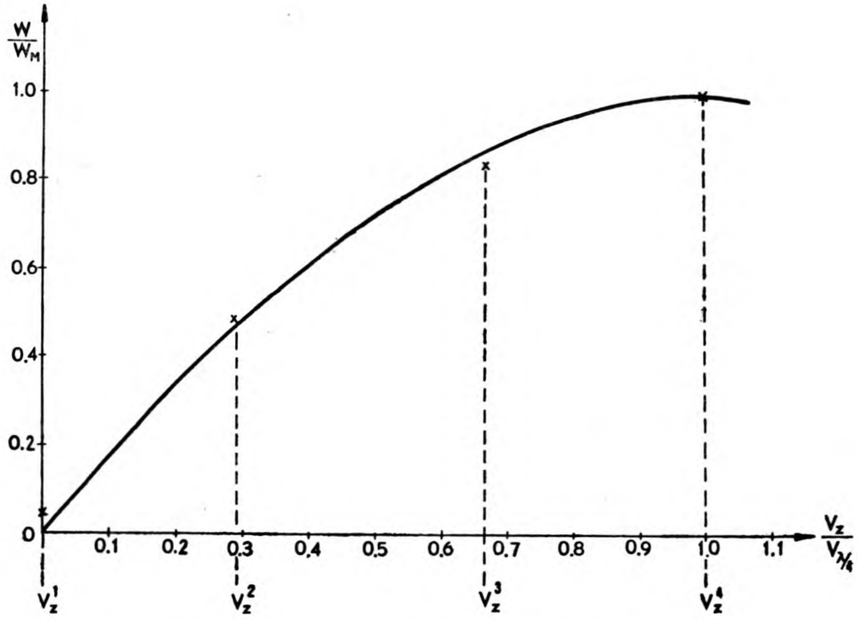

Fig. 6. Experimental results of the visibility of interference fringes as a function of V_z

4. EBS applicability in holographic investigations

The Figure 7 presents the procedure of the EBS application to holographic investigations (e.g., to a holographic interferometry). The intensities of the reference, J_r, and the object, J_s, beams are measured by means of power meters I_r, I_s – when the electronic control shutter *ES* is open. The average exposure, E_0, and the required beam ratio, *R*, are manually fixed in the control system *CS*. The average exposure, E_0, depends on the type of the sensitive material and its processing. The parameter *R* determines the exposure modulation. The control system produces automatically a voltage V_z such that the measured values of J_r/J_s ratio correspond to the required parameter *R*.

In the above measuring system *CS*, the measurement of the sum of intensities $J_r + J_s$ is simultaneously carried out in order to obtain the product $(J_r + J_s)\tau$ corresponding to the average exposure E_0. This measurement is done via an automatic fixing of the opening time τ of the shutter *ES*. Thereupon the shutter *ES* is closed.

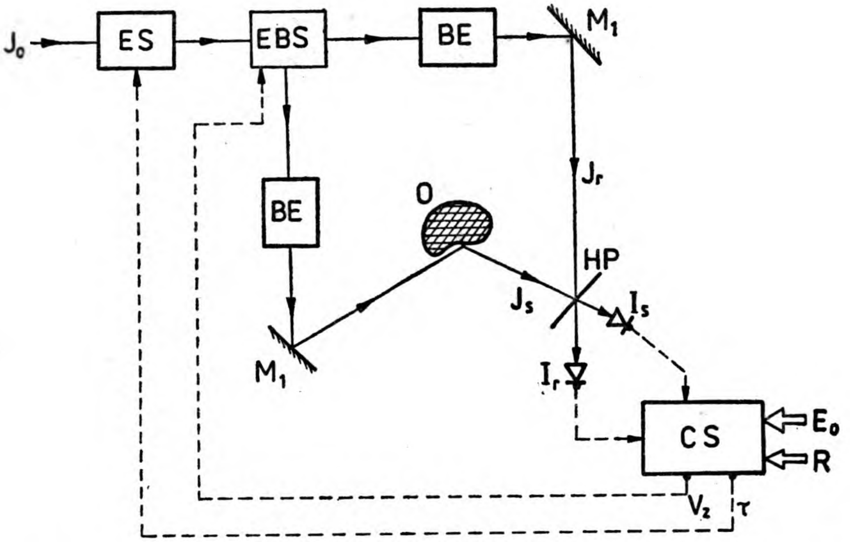

Fig. 7. Using the *EBS* in holographic investigations. *EBS* – electrooptical beam splitter, J_0, J_r, J_s – laser beam intensities, *ES* – shutter with controlled time of opening, *BE* – beam expander with *LPSF*, *O* – tested object, M_1 – fully reflecting mirror, I_r, I_s – power meters of the laser beams, *CS* – control system

The exposure of hologram takes place for the parameters τ and V_z previously fixed automatically.

In the experimental set-up (the block-scheme in Fig. 7) both the change in laser generated power and the object properties do not influence the hologram exposure parameters.

5. Summary

Summing up, the paper describes a new method of linear polarization laser beam splitting. The method proposed was verified experimentally in the interferometric investigations. The *EBS* demonstrated here is useful in other optical investigations.

References

[1] Collier R. J., Burckhardt C. B., Lin L. H., *Optical holography*, Academic Press, New York, London 1971.

[2] Helsztyński J., *Modulacja światła spójnego*, WNT, Warszawa 1969 (in Polish).

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