The rainbow hologram by the unique properties

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ABSTRACT

The report represents a new rainbow hologram, which obtains the unique properties. . This hologram is recorded by the Slitless method of rainbow hologram recording. The 1st author of this report offered the method. The method of rainbow hologram (RH) recording is a combination of the Gabor axial and the Leith- Upatnieks off-axis schemes. The narrow aperture slit is excluded in the method recording through application of the second reference wave coaxial with the object one. The holograms recorded by the method possess simultaneously the properties of the Cabor's, Leith's, Foureir's, Denisyuk's and Benton's holograms also some new properties. When the hologram is illuminated by white light several images are reconstructed in rainbow colors. These images are synchronously seen in five positions of observation: three images are seen in the transpierce rays of the $+1^{st}$, -1^{st} and 0^{th} diffraction orders; two images are seen in the reflected rays of $+1^{st}$ and -1^{st} diffraction orders. The images reconstructed in rainbow colors are synchronously seen in the five position of observation. If to introduce in the recording scheme a little change we may have a hologram with some new properties. In particular, the images reconstructed from the hologram are synchronously seen in the eight position of observation.

1. INTRODUCTION

It is necessary to remind now some common properties of holograms recorded by the basic types in schemes of hologram recording, i.e. Gabors's axis [1], Leith-Upatniek's off-axis [2], Fourier's [3] schemes. The properties of these holograms greatly different. In particular, when Fourier's hologram contacted with a lens is illuminated by a reference wave, then two images placed in opposite direction are synchronously reconstructed in plane of Fourier. Common properties of these hologram are the following:

- the two waves - a reference and a object waves - are usually used in the schemes of hologram recording.
- when the holograms are illuminated by initial reference wave or their own of the conjugate wave the virtual or the real image is reconstructed in + 1^{st} or -1^{st} orders diffraction and the observer sees only one image – real or virtual.
- zero (0^{th}) order diffraction don't have information.
- these images are reconstructed when the holograms are illuminated only coherent wave.

Benton as a two-step process of hologram recording proposed rainbow holography where a narrow aperture slit is introduced into the second stage [4]. One-step schemes for rainbow holography (RH) were proposed later on [5,6]. A narrow aperture slit restricting object wave is an inherent component of the existing schemes of one- and two-step recording schemes. The aperture slit in RH recording schemes is the main disadvantage of RH method because it increases exposures 100 to1000 times and prevents applications of this method in real time interferometry.

Therefore, the attempts to exclude the narrow aperture slim from the recording scheme or to replace this slit by an alternative hadn't success till recently. However, it was found that one could create such scheme of a hologram recording, which allows to record a hologram with unique properties. The hologram-recording scheme was offered by author of this article and named *the Slitless Scheme of Rainbow Hologram Recording* [8-13].

2. THE SLITLESS SCHEME OF THE RAINBOW HOLOGRAM RECORDING

We will consider a combination of the Gabor axial and the Leith-Upatnieks off-axis schemes, which we will name a method of the Slitless rainbow hologram (SRH) recording (fig. 1).

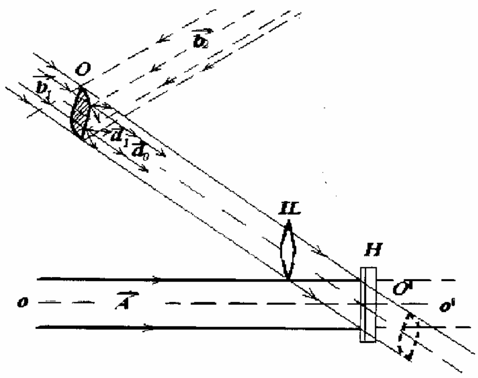

Fig. 1. The slitless scheme of the rainbow hologram recording (were O is a object; b_0 and b_1 are illuminated beems of the object- b_0 for reflecting object, b_1 for transmissive object)

The transmission factor of the transmitted object (or reflection factor of the reflecting object) may be represent in the same form of the sum, so Gabor made it [4]:

$$t(x,y)=t_0 + \Delta t \qquad (1)$$

where t_0 is a constant constituent of the transmission function with the zero spatial frequency or, a mirrior constituent of *reflecting objects;* Δt is a constituent with a nonzero spatial frequency. Then, according to Gabor [4], the object wave passing through the object can be represented as sum of

$$a(x,y)= a_0 \exp(-i\varphi_0)+a_1\exp(-i\varphi_1) \qquad (2)$$

where a_o and a_1 are the amplitude of the coherent back ground or of the mirror wave and scattered waves, respectively, which are determined by the constituents t_0 and Δt; φ_0 and φ_1 are the phases of these waves. The scheme operates with three waves :

$A = A\exp(-i\psi)$ is the off axis reference wave;
$a_0 = a_0\exp(-i\varphi_0)$ is coherent background *(it plays the role of the second reference wave);*
$a_1 = a_1\exp(-i\varphi_1)$ is the object wave;

Intensity light incident at the photoplate is defined as

$$I(x,y) = |A \exp(-i\psi) + a_0 \exp(-i(\varphi_0 + \gamma)) +a_1 \exp(-i(\varphi_1 + \gamma))|^2 = A^2 + a_0^2 + a_1^2 + 2 a_0a_1 \cos(\varphi_1 - \varphi_0) + 2 Aa_1 \cos(\gamma + \psi - \varphi_1) + 2 Aa_0 \cos(\gamma + \psi - \varphi_0), \qquad (3)$$

where $\gamma=2\pi\alpha x$, $\alpha = \sin\theta/\lambda$ is spatial frequency, λ is length of the recording wave, A^2 is background illumination, a_0^2 is coherent background, a_1^2 is negative blurred image of the object. Here three holograms are recorded in the photoplate: the first one,

$\tau_1 = 2a_0a_1 \cos(\varphi_1 - \varphi_0)$ describes the Gabor hologram; the second one,
$\tau_2 = 2Aa_1 \cos(\gamma + \psi - \varphi_1)$ corresponds to the Fresnel hologram ; and the third one
$\tau_3 = 2Aa_0 \cos(\gamma + \psi - \varphi_0)$ represents the regular space holographic grating (RSHG) with spatial frequency α. It may also work as holographic lens, where $\gamma = 2\pi\alpha x$, $\alpha = \sin\theta/\lambda$ - spatial frequency.

When the hologram is illuminated with a wave coinciding with the initial reference wave, A(*k*), three light beams are generated behind the hologram and they correspond to 0 and $\pm 1^{st}$ orders of diffraction (*fig.2)*:

$$U(k) = A(k)\, t(x,y) = U_0(k) + U_{+1}(k) + U_{-1}(k) \tag{5}$$

Let us find intensities of fields of the 0 and ±1st diffraction orders behind the hologram [12] :

$$I_0 = A^2[1 - 1/2(\tau_3^+\tau_2^- + \tau_3^-\tau_2^+) + 1/4(\tau_1^+\tau_1^- + \tau_1^-\tau_1^+ + \tau_1^+\tau_1^+ + \tau_1^-\tau_1^-)] \tag{6}$$
$$I_{+1} = A^2/4[(\tau_3^+\tau_3^- + \tau_2^+\tau_2^-) + (\tau_3^+\tau_2^- + \tau_3^-\tau_2^+)] \tag{7}$$
$$I_{-1} = A^2/4[(\tau_3^-\tau_3^+ + \tau_2^-\tau_2^+) + (\tau_3^-\tau_2^+ + \tau_3^+\tau_2^-)] \tag{8}$$

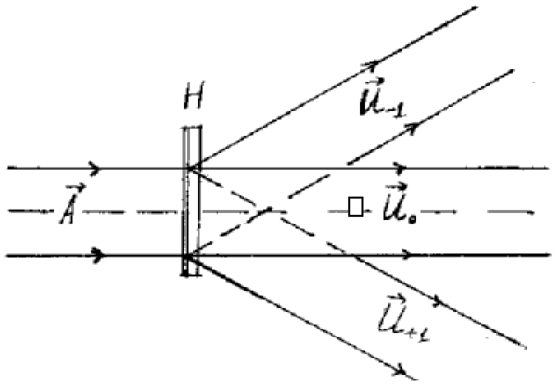

Fig. 2. Scheme for illumination of the hologram recorded according to the scheme in figure 1.

The expression for intensities has the combinations and correlation of the different types holograms. The meanings of these combinations and correlation are given in [12].

The narrow aperture slit is excluded in the slitless method of RH recording through application of the second reference wave coaxial with the object one. As a result, three holograms are being recorded simultaneously on a photographic plate: an axial Gabor's hologram, an off-axial Fresnel's hologram and a regular holographic grating (RHG), moreover, the off-axial hologram and RHG possess the same spatial frequency. Existence of a RHG in a hologram is the cause of new feature: object images are reconstructed in rainbow colours when such a hologram is illuminated with white light [9,10]; when it is illuminated with laser light a number of new object images, besides, the virtual and the real ones, are generated, in particular, continuous projective images are being transferred simultaneously in the three diffraction orders[8]; if an object is a regular one (for example, a diffraction grating) then under coherent light illumination we can observe a self-imaging of the grating simultaneously in the three diffraction orders (the Talbot effect in holography) [11].

The report also shows the common physical nature of the phenomena that seems at first rather distant from each other: of rainbow holography and the Talbot effect in holography, and it proposes a theory of slitless RH and of the Talbot effect in holography developed from a unified point of view[12].

The hologram recorded by such method possesses some new properties [9]. Note that one of the peculiarities of the hologram is that it is the amalgamation of Gabor's[4], Leith's[5], Fourier's [6] and Benton's[1] holograms into one hologram.

A further investigation of the method SRH had reduced to amalgamation Gabor's, Leith's, Benton's and Denisyuk's holograms into one hologram [13]

3. THE EXPERIMENTS

The objects of holographing were have chosen a reflecting (a jubilee coin of one rouble) and transmitting (a rouse branch made from crystal, transparent and periodical diffracted grating) objects.

For a jubilee coin the second off-axis reference wave was received by partially polished of a surface of the coin. The holograms were have recoded with the scheme fig 1. The scheme of reconstructing of the imaging had shown in fig 3.When the holograms are illuminated by white light the images are reconstructed in rainbow colours.If to introduce in the recording scheme hologram a little change we may have a hologram with some new properties. The reconstructed images in rainbow colours from such hologram are synchronously seen in five positions by of observation. (Fig.3):

▪ observers l and 5 see the **real** images of the object;

▪ observers 3 and 4 see the virtual images of the object; observer 2 sees the virtual or real image in a powerful background of the **zero** order diffraction.

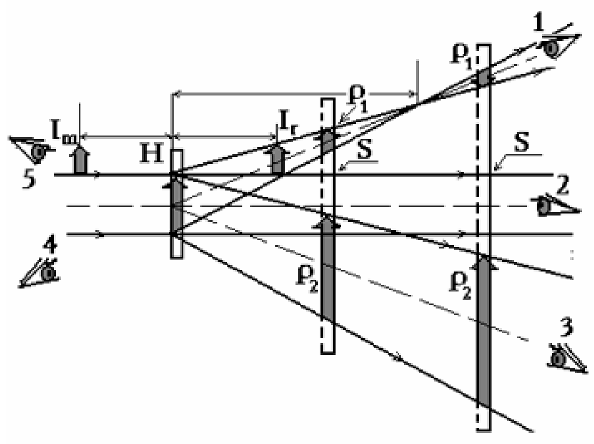

Fig. 3. The scheme for illumination of the hologram recorded with the scheme in fig.1.

These **new properties** are consequence of accomplishment of the Fourier and holographic lens recording in the new scheme hologram recording. If to introduce in the recording scheme a little change we may have a hologram with some new properties. In particular, the images reconstructed from the hologram are synchronously seen in the **eight position** of observation

4. CONCLUSIONS

1. The holograms recorded by the SRH Scheme possess simultaneously the properties of the Cabor's, Leith's, Foureir's, Denisyuk's and Benton's holograms and some new properties.

2. The images reconstructed in ranbow colours are synchronously seen in the five position of observation.

3. If to introduce in the recording scheme a little change we may have a hologram with some new properties. In particular, the images reconstructed from the hologram are synchronously seen in the **eight position** of observation.

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