New Method of the Rainbow Hologram Recording

A. Maripov
Kyrgyz Technical University, 720044 Bishkek
Republic Kyrgyzstan

Abstract

The new method of the rainbow hologram recording is described in the paper. The holograms recorded by the new method will samiltenously obtain Gabor's, Fresnel's, Fourier,s, Benton's and some anothers unique properties.

1. Introduction

Rainbow holography was proposed by Benton as a two-step process of hologram recording where a narrow aperture slit is introduced into the second stage.[1] One-step schemes for rainbow holography (RH) were proposed later on.[2,3] **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. 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,[4] Leith-Upatniek's off-axis,[5] Fourier's[6] schemes, also Benton's scheme of a rainbow hologram recording[1] and Denisyuk's scheme of a reflected hologram recording.[7] 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 + 1st or -1st orders diffraction and the observer sees only one image – real or virtual;
- zero (0th) order diffraction don't have information

However, it was found that one can 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.[8-12]

Therefore, the attempts to exclude the narrow aperture slim from the recording scheme or to replace this slit by an alternative haven't success till recently.

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.[6] Note that one of the peculiarities of the hologram is that it is the amalgamation of Gabor's,[8] Leith's,[9] Fourier's and Benton's[1] holograms into one hologram.

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 have named the Slitless method of rainbow hologram recording (fig. 1).

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[7]:

$$t(x,y) = t_0 + \Delta t, \tag{1}$$

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,[7] the object wave passing through the object can be represented as sum of

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

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.

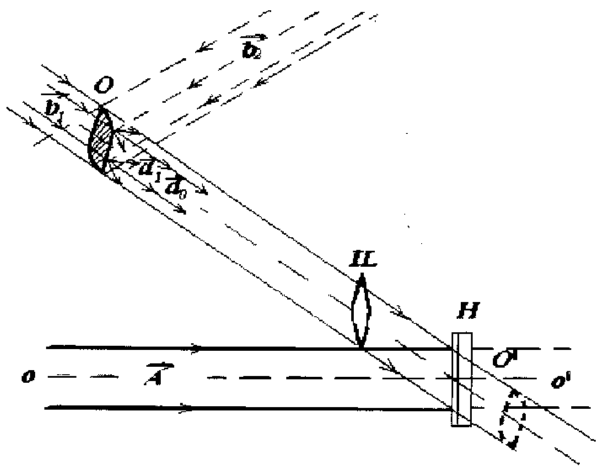


*Figure 1. The slitless scheme of the rainbow hologram recording (were **O** is a object; $\boldsymbol{b_0}$ and $\boldsymbol{b_1}$ **are** .illuminated beems of the object- $\boldsymbol{b_0}$for reflecting object, $\boldsymbol{b_1}$for transmissive object)*

The scheme operates with three waves:
A = $A\exp(-i\psi)$ is the off axis reference wave;
$\boldsymbol{a_0} = a_0\exp(-i\varphi_0)$ is coherent background *(it plays the role of the second reference wave);*
$\boldsymbol{a_1} = a_1\exp(-i\varphi_1)$ is the object wave,

Intensity light incident at the photoplate is defined as

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

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 holographical lens; where

$$\gamma = 2\pi\alpha x, \ \alpha = \sin\theta/\lambda.$$

The fulfillment of the conditions $A \geq a_0 \geq a_1$ follows from the requirement of the sufficient diffraction efficiency of the hologram obtained (Gabor's and Fresnel's) and the holographic grate. Such a hologram is recorded *in materials with phase modulation* and processed in the linear mode (Γ = -2) and bleached in a way that to convert it into a *phase* one.

Transmission of such a hologram is expressed with three exponential terms

$$t(x,y) = \exp(iI(x,y)) = \exp(i\tau_1)\exp(i\tau_2)\exp(i\tau_3), \qquad (4)$$

According to all the above disclosed, it follows from expression (11) that, 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 ±1[st] orders of diffraction (fig. 2)

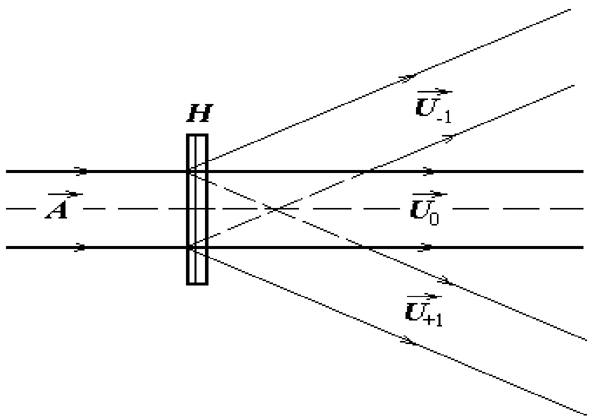


Figure 2. Scheme for illumination of the hologram recorded according to the scheme in Figure 1.

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

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

$$I_0 = A^2[1 - 1/2(\tau_3^+\tau_2^- + \tau_3^-\tau_2^+) + 1/4(\tau_1^+\tau_1^- + \tau_1^-\tau_1^+ + \tau_1^+\tau_1^+ + \tau_1^-\tau_1^-)], \qquad (7)$$

$$I_{+1} = A^2/4[(\tau_3^+\tau_3^- + \tau_2^+\tau_2^-) + (\tau_3^+\tau_2^- + \tau_3^-\tau_2^+)] \qquad (8)$$

$$I_{-1} = A^2/4[(\tau_3^-\tau_3^+ + \tau_2^-\tau_2^+) + (\tau_3^-\tau_2^+ + \tau_3^+\tau_2^-)] \qquad (9)$$

The expressions for intensities have had the combinations and correlation of the different types holograms. The meanings of these combinations and correlation are given in Ref. 12.

3. Results of the Experiments

3.1. Holograms of the Reflecting Objects

A **jubilee coin** of 1 rouble have been chosen as the reflecting object for the experiment. Here the second off-axis reference wave was received by partially polished of a surface of the coin. When the hologram is illuminated by **white light** the images are reconstructed in rainbow colours (Fig. 4).

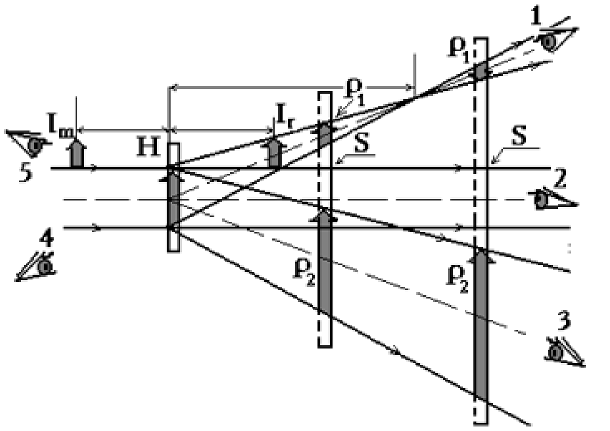


Figure 3. The scheme for illumination of the hologram recorded with the scheme in fig.1.

These images are **synchronously** seen in five position of observation (Fig. 3):

- observers 1 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

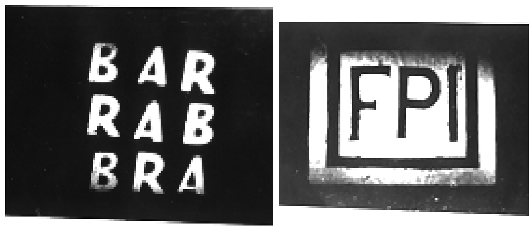
These new properties are consequence of accomplishment of the Fourier and holographic lens recording in the new scheme hologram recording.

Holograms of the Transmitted Objects

The transmitted objects have chosen **a rouse branch** made from crystal, **transparent** and **periodical diffracted grating.**

Figure 4. Black-and-white photo of the rainbow image of a COIN

Figure 6. Black-and-white photo of the rainbow image of the ROSE BRANCH.



A B

Figure 7. Black-and-white photos of the rainbow images of the transparents: A: fragment of a text; B: black letters on the transparent background

- The images of the objects are reconstructed in rainbow colours when the hologram is illuminated by **white light** (Fig. 6, 7).

These images are also **synchronously** seen in the five positions of observation (fig. 3).

- If the hologram of the transmitted objects is illuminated by **coherent light**, then in addition to traditional the real, I_r, and virtual, I_m, images there are reconstructed the Gabor-image of the object in the zero diffraction order, which not shown in this figure; two projectional images, P_1 and P_2, continuously transferred along the rays of the ±1 st orders of diffraction; these images can be observed on the diffuse screen, S, located in the way of these waves, and in the extreme limit, these images coincide with the focused object image on the hologram itself [fig. 3]. Some other images appear under these conditions of recording and illumination.

The holograms of **the *periodic grating*** recorded by the above scheme possess more interesting properties.

When the hologram was illuminated by a plane *monochromatic wave* the grating self-images besides the traditional real and virtual images of the grating (which are not shown in the figures), were reconstructed simultaneously at certain distances, not only in the rays of the +1st and -1st diffraction orders, but also in the straight direction (the zeroth order) (fig. 8). In the figures, the positions of the self-imaging planes of the positive and negative images of the grating itself are denoted by *SI* and *SI'*; those reconstructed from the hologram are denoted by

SIH and *SIH'*, respectively (O^1 is the grating position during the hologram recording).

In the real image region, the distance from the hologram to the self-image planes, z, for the +1st and -1st orders is defined by the expressions, respectively:

$$z^{+} = p\,\Delta z - z_1\,;$$
$$z^{-} = p\,\Delta z + [z_1 - E(z_1/\Delta z)\Delta z], \qquad (10)$$

where z_1 is the distance between the object and the hologram during its recording, $E(a)$ is the integer part of number a. p =0, 1/2, (1+1/2), ..., (j+1/2), j = 0, 1, 2, 3, ... - the integer number, integer and semi-integer values of p indicate the planes of the positive and negative grating self-images, respectively. Note, that the distances from the hologram to the self-image planes in the direction of the zero order are equal to $z^0 = z^{-} \cos\theta$.

The positions of the self-imaging planes z^+ and z^-, in the directions of the +1st and -1st orders diffraction are determed according to formula (10) .

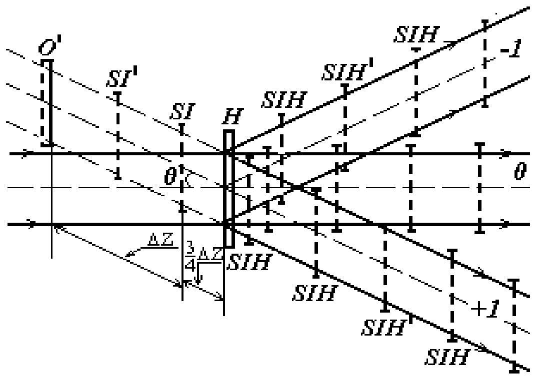


Figure 8. Scheme of reconstruction of self-images from the periodic grating holograms

4.Conclusions

1. The holograms recorded by the Slitless Scheme possess simultaneously the properties of the Cabor's, Leith's,Foureir'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. Subsequent use of this scheme in hologram recording of the regular objects have led to discovery of a new phenomenon - the Effect Talbot in Holography.[11]
4. We have established the common physical nature of the rainbow holography and the Talbot effect in holography and have created the theory of this phenomenon with the application of the modulation theory and Fourier analysis of optical signals.

References

1. Benton S.A., *J. Opt. Soc. Am*., 1969, v. 59, p. 1545.
2. Chen H., Yu F.T.S., Tai A.M., *Opt. Lett*., 1978, v. 2, p.85.
3. Grover C.P., Lessard R., *Appl. Opt.,* 1983, v. 22, p. 2300.
4. Gabor D., Microscopy by reconstructed wave fronts. *Proc. Roy. Proc (London),* 1949. A197, p.454
5. Leith E., Upatnieks J. Reconstructed wave fronts and communication theory. *Opt. Soc. Amer. l962, v.52, p.*ll*23.*
6. Goodman J.W. Introduction to Fourier Optics, McGraw-Hill, N.Y., 1968.
7. Denisyuk Y.N. DAN SSSR . 1962, v.144, 1275 (Russian text)
8. *Maripov A. Specific Features of Transmissive Object Holograms.* J Optics (Paris).
9. Maripov A. New Aspects in Rainbow Holography. *J. Optics (Paris),* 1991; 22:297-301.
10. Maripov A. Slitless and Lensless Rainbow Holography, 7. *Optics (Paris),* 1994; 25: 131-133.25:3-8
11. Maripov A., Ismanov J. The Talbot Effect (a Self-Imaging Phenomenon) in Holography. *J. Appl. Phys*., 1993, v. 24, #8, p. 7039.
12. Maripov A. Theory of the slitless rainbow holography and the Talbot effect in holography. *Optics (Paris), 1995, v. 26 #5 ,p. 201 -208.*

Biography

Arapbay Maripov received his high education in Physics from the Physics Department of the Moscow State University (Moscow City) in 1964 and *highest degree-* Candidate of Physics and Mathematics, from Moscow State University in 1971. He received degree Ph.D (Physics and Mathematics) from Institute of Physics of the Kyrgyz Academy of Sciences (Kyrgyz Republic) in 1994. Since 1970 he has worked in Kyrgyz Technical University. He is professor and head of the Department of Applied Physics of the Kyrgyz Technical University. His work has primarily focused on the research of the Optical holography. In particular he offered new method of the rainbow hologram recording-Slitless Scheme of the Rainbow Hologram Recording.

He is the active member of the New York Academy of Sciences, Regular member of the International Society for Optical Engineering (SPIE), Holography Working Group of SPIE.