Acoustooptical Approach for Moving Scene Holography

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Abstract: At the paper the method of 3D holographic moving image reconstruction is discused. The main idea of this method is based on the substitution of optically created static hologram by equal diffraction array created by acoustical (AO) field which formed by bulk sound waves. Such sound field can be considered as dynamic optical hologram, which is electrically controlled. At the certain moment of time when the whole hologram already formed, the reference optical beam illuminates it, and due to acoustooptical interaction the original optical image is reconstructed. As the acoustically created dynamic optical hologram is electronically controlled, it can be used for moving 3-dimentional scene reconstruction in real time.

The architecture of holographic display for moving scene reconstruction is presented at this paper. The calculated variant of such display laboratory model is given and discussed. The mathematical simulation of step by step images recording and reconstruction is given. The pictures of calculated reconstructed images are presented. The prospects, application areas, shortcomings and main problems are discussed.

1. INTRODUCTION

There are several scientific groups in all over the world what are devoted their research to the attempts for bulk holographic video systems design and development (see for example [1-25]). At the present paper the method of moving image reconstruction based on the acoustooptical (AO) interaction is considered. The first suggestion of this principle for surface sound wave field generated by anti-phased electrodes piezotransducers was done in 1994 [17]. The main difference of the method offered in [20] consists in application of bulk but not surface acoustic waves. That leads to achievement of following advantages: 1) optical diffraction on bulk sound waves gives much higher diffraction efficiency which stipulated by large area of light-sound interaction. 2) multielement system of bulk sound waves radiators allows to generate mainly just unique petal of directivity diagram. That allows not to assume as it was considered in [17], that radiation system has two-lobs directivity diagram which stipulates additional distortion of sound field when reflecting from side edges; 3) the hologram offered in [20] can be considered as thick hologram (named sometimes as Denisyuk hologram). Such thick hologram realizes the Bragg regime of light diffraction and it possessed by the features of spectral and spatial selectivity. These features can not be realized with thin hologram formed by surface acoustic waves. The method of Bragg optical dynamic hologram, which is created by bulk acoustical wave field for moving image reconstruction was offered in 1996 [20] and developed then in [23-25].

There set of problems meet at the way of such system construction.

1) It is necessary to find for acoustooptical interaction the medium with low sound attenuation and high figure of merit. This is important because of necessity to excite the sound field at very high frequencies so that to reach as small sound wave lengths as optical waves have. In this case the spatial resolution can be comparable with usual optically created

hologram. Besides the bandwidth of acoustooptical interaction must be very large to allow the excitation of a large range of spatial frequencies at the hologram to translate maximum data and not to loose some information about reconstructed image. Today already known the experimental works in realization of very wide band (up to 3 GHz) and very high frequencies (up to 10GHz) acoustooptical interaction [26]. At such high frequencies the sound wave lengths are already comparable with optical the wave lengths. Of course up to now the sound attenuation is still very high in know materials.

2) To repeat in acoustically created optical hologram the exact transparency spatial distribution of optically created hologram (or try to approximate it as exactly as possible) it is necessary to find the mechanism of complicated sound field distribution realization. One of possible ways is to use digitized approach of exciting the sound field by the array or line of electroacoustical transducers. The electrical signal to each transducer is leaded from the driver where the time and spatial distribution of electrical field is numerically created. This distribution is previously calculated by the computer (or given from the real time recording system). Such an approach requires the creation of very small point sound radiators displaced to the array or line with a period that is compared to a sound wave length.

3) To calculate in real time such complicated electrical signal's distribution a very high-speed processor is required.

The consideration of main principles of acoustooptical holographic moving image reconstruction and the main problems discussion is the very aim of present work.

2. ACOUSTO OPTICAL SYSTEM ARCHITECTURE FOR 3-D MOVING SCENE RECONSTRUCTION DISCUSSION

As it seems the first idea to consider the AO cell as kind of hologram in fact belongs to A. Korpel [27-29] when considering the application of acoustooptics for image Bragg visualization, as it was shown that the AO cell is possessed by hole features of hologram.

Let us consider now one of possible variants of system architecture for holographic moving image AO reconstruction (Figure 1).

The display itself represents the plate of AO interaction media (1) with sizes H x D (See Figure 2). On one of the butt end of this pate the multielement system of sound radiators (2, Fig.1) are disposed. The electrical pulse signals are directed to each element from the controlling processor (7) and drivers (3,4), that calculates and generates the necessary amplitude and phase of each signal in accordance to special algorithm. Such an algorithm provides the building of certain sound field distribution (dynamic hologram (11)) on far field area with sizes A x B at the maximum distance H from the transducer's plane (Fig.2.). This sound field distribution can be previously calculated by the computer, taking into account and correcting sound attenuation, pixel's shape distortion and other possible effects that deteriorate the recreating image. The set of electrical signals which feeding the sound radiators might be also retranslated from the image receiving system (which is the topic of separate consideration) so that to reconstruct the imaging scene in the real time.

The spatial resolution of AO imaging reconstruction system is mainly depended on the sound wave length Λ, the period of an array l, the duration of electrical pulse τ_S, which feeds each sound radiator, and the duration of optical reference pulse τ_L, which illuminates the hologram when recreating the image. Thus not taking into account the distortion effects the spatial resolution in the plane in parallel to the transducer's array (along y axis) is $\Delta y = l$, and along the normal to transducer's plane (x axis) is $\Delta x = V\tau_L$, where V is the sound velocity. The unique pixel duration τ_S must not to exceed and be synchronized to the duration of reference light pulse τ_L . The sizes of each piezo element are: L - length and H - height. The spatial period l of transducer's array has to be comparable to the acoustical wave length Λ so that to provide the sufficient divergence γ of sound beam in the plane of hologram (see Fig.2.). The sequence of electronically controlled and acoustically created optical holograms moves in the space continuously from the transducer's plane along the x-axis. It is assumed that the whole hologram of each particular image is formed in the far the field (A x B) area. Once the particular hologram is formed, the optical light pulse is on and the particular image is recreated. The consequence of reference light flashes has the spatial period T which is in fact defined by the time of sound transmission from the transducer's plane to the end of the display ($T= H/V$). The reference optical beam from the laser (5) (Fig.1.) is formed in time by pulse modulator (6) and in space by lens. The moving 3D holographic image (9) that is recreated due to acousto-optical effect can be seen by the observer (8) in the direction of first order of Bragg diffraction. The optical polarizer (10) is used for cutting of unused zero order diffracted light. The Bragg regime is provided when the Klein-Cook parameter $Q \geq 4\pi^2$ ($Q = 4\pi^2 L/\Lambda^2\lambda$).

There are several reasons to chose the Bragg regime of light diffraction on bulk acoustic waves:

1. To get the appropriate efficiency of AO interaction;
2. To provide the image reconstruction, just in unique first order of diffraction.
3. To reach very high sound frequencies (very small diffraction array's periods) so that to enhance the spatial resolution.
4. To obtain very big frequency bandwidth so that to enlarge the spectrum of spatial frequencies of hologram and to decrease the image distortion.
5. In the case of Bragg light diffraction on the bulk acoustic waves the acoustically created optical dynamic hologram at its feature is equivalent to the thick 3D hologram (called also as hologram of Yu. Denisyuk) [30]. That means, that such a hologram possess by the feature of selectivity to the optical wave length λ.
6. When using an anisotropic Bragg diffraction it is possible to cut the useless zero order of diffraction by the polarizer as the polarization of image light is turned to $\pi/2$ in this case as compared with the zero (undiffracted light) order.

The calculations shows that small laboratory model of holographic display with working area 2.56 x 2.56 cm^2 and space resolution 175 x 100 mμ^2 can be designed by using the TeO$_2$ photoelastic media. The diffraction efficiency 0.16% per 1 mW of electrical power can be obtained.

3. COMPUTER MODELLING OF ACOUSTICALLY CREATED OPTICAL HOLOGRAM

In [17, 31] on the basis [32, 33] the algorithm of numerical evaluation of acoustically created optical hologram was build. In [25] this theory was developed for the medium with sound attenuation; the thick acoustically created optical hologram was considered. At the same work the method of static modeling of dynamic electronically controlled hologram was developed.

Taking into account the restriction of space for this paper we will not be consider the mathematical description of step by step evaluation of holographic process. We just consider the main ideas for these steps realization and discuss the numerical simulation results.

Recording process of electronic hologram

Step 1. Admission that the 3-dimensional (3D) recording object hologram can be represented as a superposition (with phase shifting) of single-plane hologram [31].

Step 2. Expression of the scalar field in the hologram plane through the Fresnel-Kirchhoff integral and representation it as 2D convolution of pulse spatial reply (reference field) with 2D input (object) signal.

Step 3. Representation at the Fresnel approach of the field intensity distribution at the given distance from the object plane (mathematical Fresnel hologram).

Note.

This mathematical Fresnel hologram represents the field intensity distribution at the hologram plane. Such field intensity distribution can be used then for the creation of physical hologram. For example it can be done by illuminating with this field of the photo plate. It is alluring also to admit that with this field is possibly to create by some way the momentary distribution of acoustical waves in photoelastic medium. Avoiding now the discussion of mechanism of optical induction of sound wave hologram, we just assume that such necessary sound waves distribution is done*.

Step 4. It is assumed that the spatial distribution of elasto-optical medium refractive index variation, which is created by sound waves excited by the array of transducers at the fixed moment of time, exactly repeats the space distribution of optical hologram transmission function variation. This assumption means the equivalence of each spectrum components of these optical and acoustical fields. So the Fourier transform of obtained field distribution in hologram plane is written. This equation evaluated in such a way that it takes into account the compensation of sound attenuation influence of each component of acoustical field.

Step 5. The equation which is defined the correspondence between angular spectrums of acoustical field and the angular spectrum of electrical signals excited by sound field in the transducer's array was specially evaluated. This equation in fact substitutes one of two space coordinates of acoustical field momentary distribution by time coordinate taking into account the sound waves features. By using this formula the expression describing the time depended electrical signals distribution along the transducer's array can be written.

Step 6. By back Fourier transform of last equation the expression for time-space electrical signals field distribution can be written.

Step 7. Simulated set of electrical signals can be then used for 3D holographic image reconstruction. It is assumed that in real device these signals are amplified and transmitted to the reconstruction system.

Reconstruction process represents the inverted steps of recording process:

- Two dimensional space-time depended field of electrical signals is applied to the electro-acoustical transducer's array;
- By Fourier transform of the expression for these signals time-space distribution the spectrum components of electrical signal's can be found.

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* The question of sound wave hologram recording is the separate interesting problem, which is not the aim of present paper and it will be discussed in next publications.

- Using the equation for coordinates transformation which defines the correspondence between angular spectrums of electrical signals, leaded to the transducer's array, and the angular spectrum of excited acoustical field, the spectrum components of last one are found;
- By back Fourier transform the sound field two dimensional distribution can be written;
- The reconstructed optical 3D image can be formed by using the equation for mathematical hologram when the hologram is illuminated by the same reference optical field as during the registration process.

4. EXAMPLE FOR NUMERICAL SIMULATION OF ACOUSTICALLY CREATED OPTICAL HOLOGRAM AND 3-D MOVING IMAGE RECONSTRUCTION

Figure 3 shows the sequence of steps for electrical signals set forming when recording the sound waves optical hologram. The optical field from 2-D single-plane object (1) illuminates under the Bragg angle at the certain distance the hologram plane. Simultaneously the reference field illuminates the same plane. At picture (2) the convolution corn function at the hologram plane is presented. Calculated mathematical Fourier hologram is given at (3). Fourier transform of this field is shown at Fig.3 (4). After transforming of coordinates this angular spectrum looks like it shown at (5). Back Fourier transform gives us the time-space distribution of electrical signals at the transducer's array (6).

Figure 4 shows the 3D holographic image reconstruction process. Electrical signals set feeding the transducer's array is given at Fig. 4 (1). At (2) the Fourier transform of this field is shown. After coordinates transformation it looks like it shown at (3). The dynamic sound waves optical hologram at the certain time moment looks like it shown at Fig.4 (4). At the last two pictures (5) and (6) the reconstructed bulk images are given for different time moments.

Figure 5 illustrates the bulk image reconstruction from static optical, and dynamic acoustically created optical holograms. 1) one-plane of 3-D object image; 2) static optical hologram of this image; 3) dynamic acoustically created optical hologram; 4) object image, reconstructed from static optical hologram; 5) object image, reconstructed from acoustically created dynamic optical hologram at the time with factor 1.2 of illumination pulse period; 6) this image, reconstructed at the time exactly synchronized to illumination pulse.

6.CONCLUSION

The fulfilled numerical modeling shows the prospects in the development of holographic video on the basis of acoustooptical approach.

At the same time one can meet the number of problems at this way. The main of them are:

1. The necessity to develop a new acoustooptical material with low sound speed, low sound attenuation and big figure of merit. (This is the common problem of whole acoustooptics).
2. To be able to create the complicated sound field distribution which can approximate at the certain moment of time the real optical hologram.
3. To find the way of real time image hologram electronically fixing for following processing, transmission and 3D image reconstruction.

From the other hand in spite of the before mentioned problems, already today we have the real objective possibilities for the creation of laboratory model of holographic video system which based at the acoustooptical approach. Such small electronically controlled holographic systems can be applied, for example, for creation of real time bulk image holographic microscopy.

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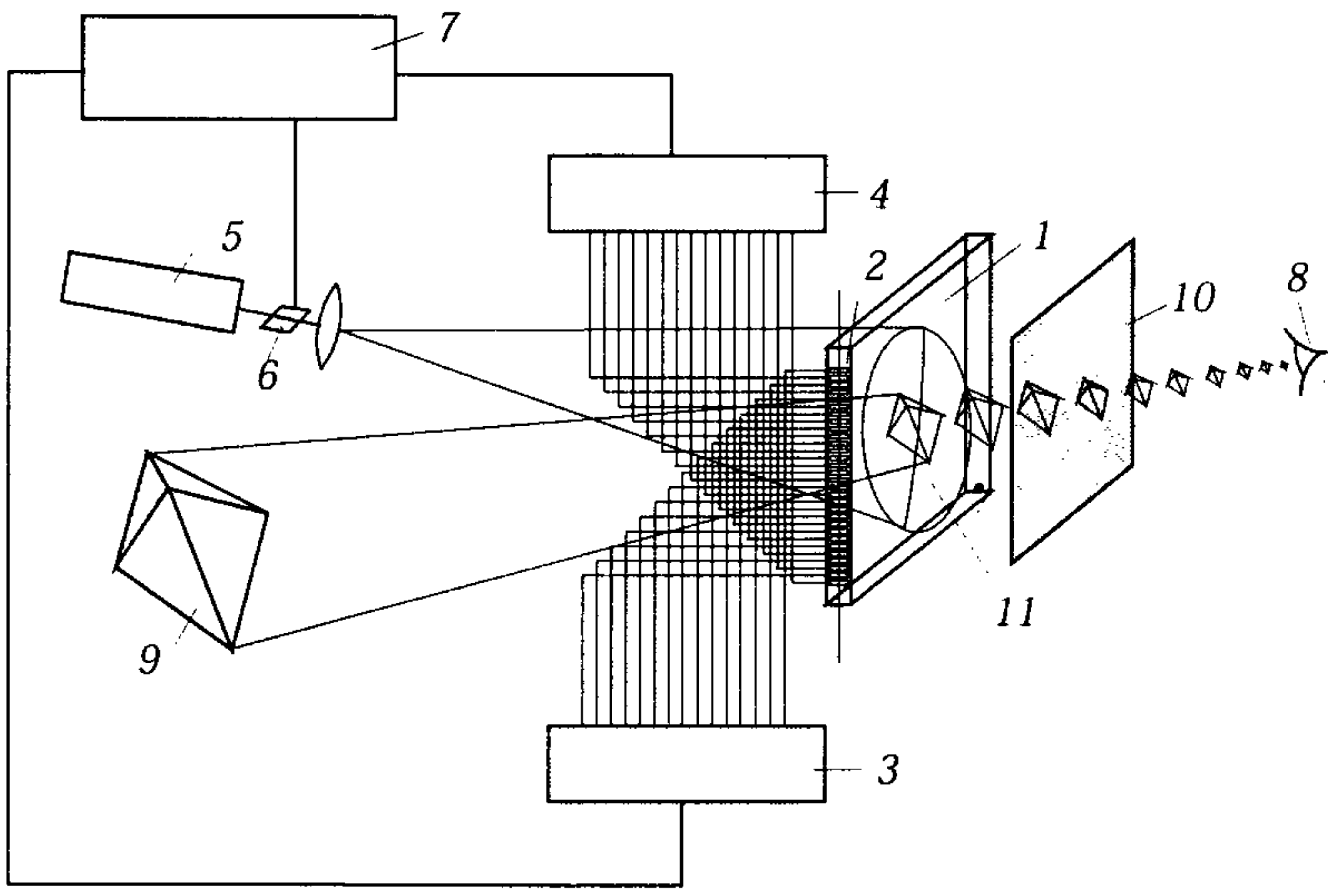

Figure 1 . Architecture of acoustooptical display.
1- elastooptical medium; 2 - transducer's array;
3,4 - electronical drivers; 5 - laser; 6 - illuminating pulse modulator; 7 - controlling system; 8 - observer;
9 - reconstructed object image; 10 - polarizer;
11 - sound waves dynamic optical hologram.

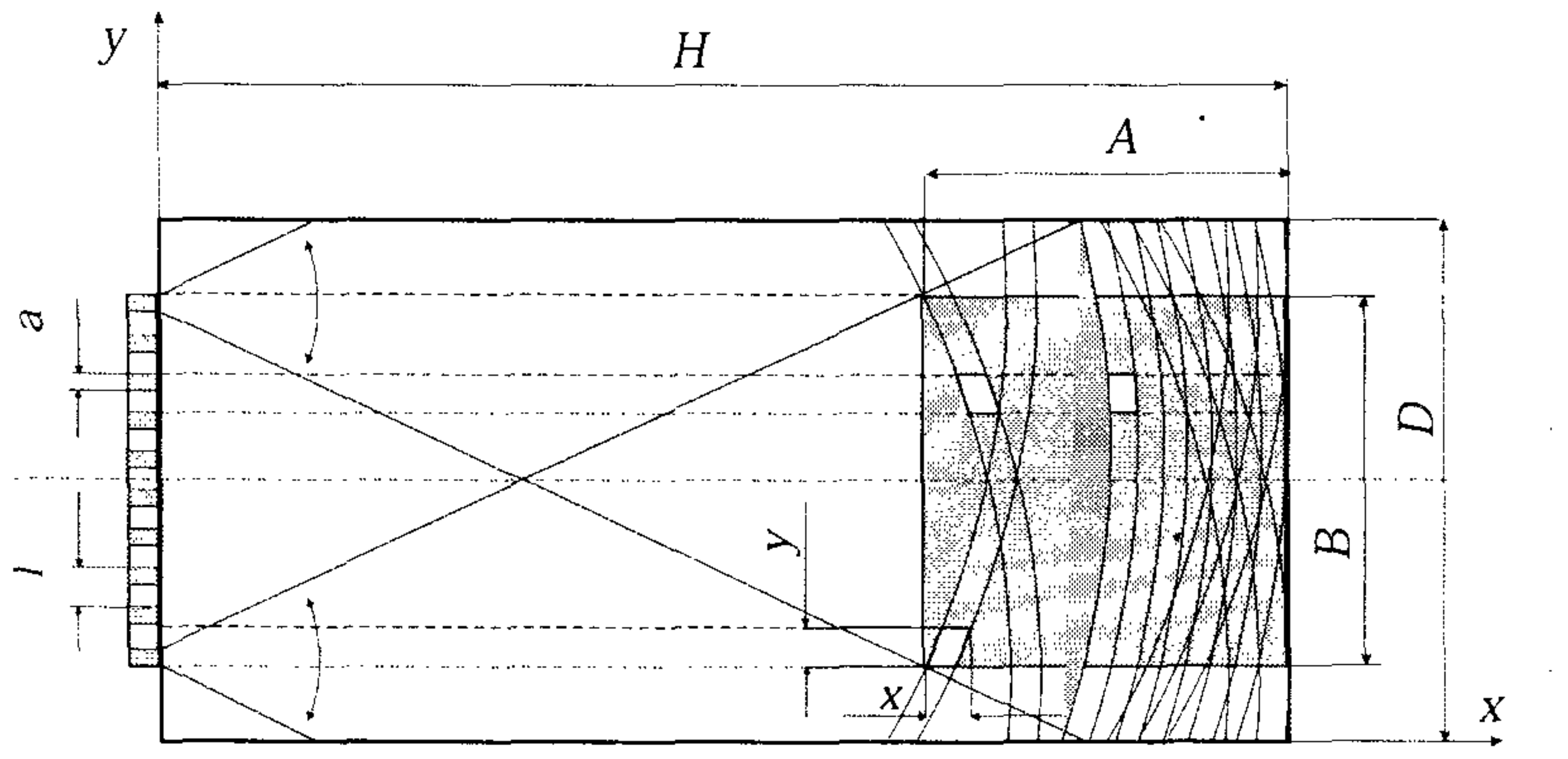

Figure 2 . The scheme of sound wave dynamic optical hologram forming.

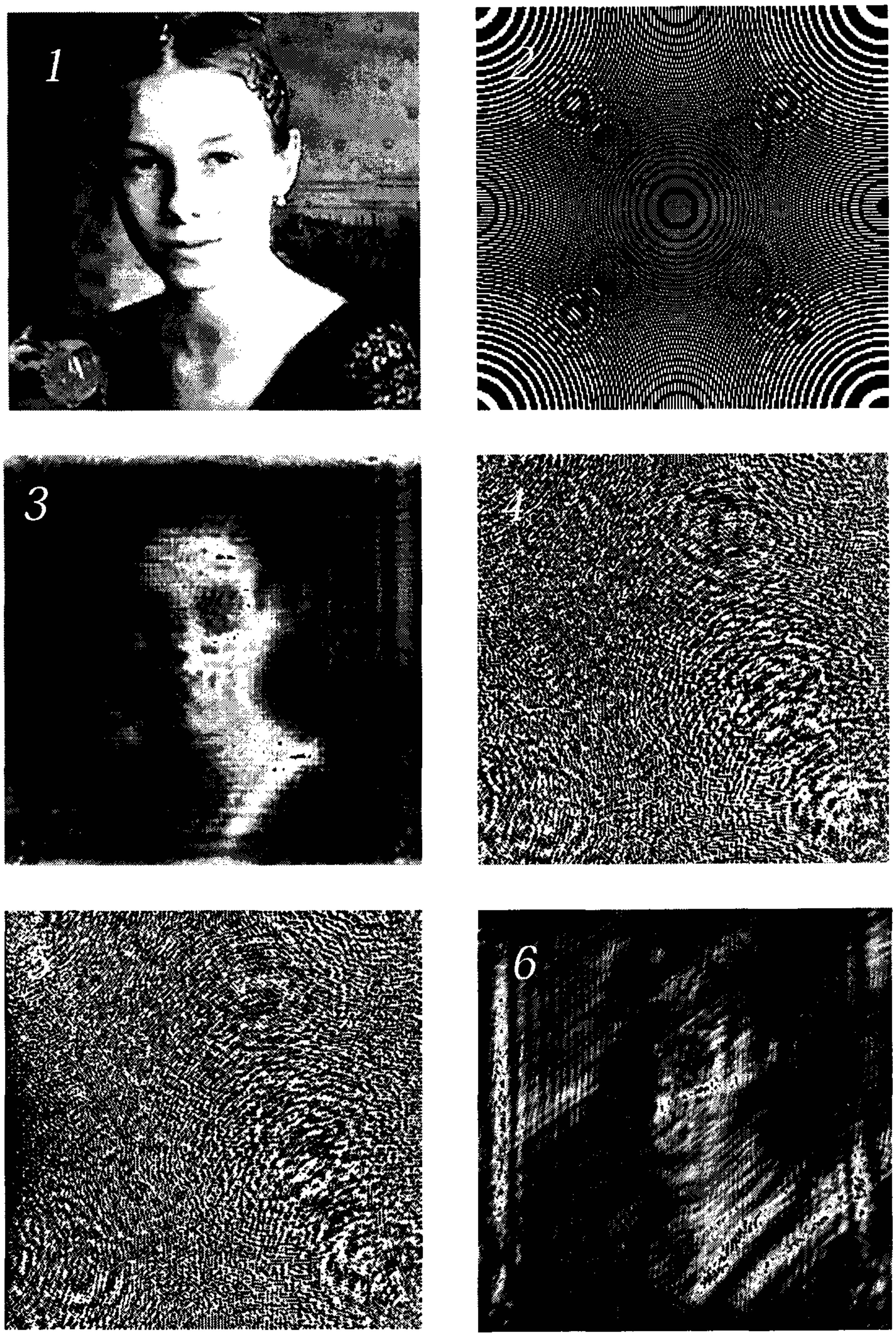

Figure 3 . Optical image holographic recording and to electrical signals transformation illustration. 1) one plane of 3-D object; 2) convolution corn function; 3) object's optical hologram; 4) Fourier-image of optical hologram; 5) this Fourier-image after coordinates transformation; 6) electrical signals field.

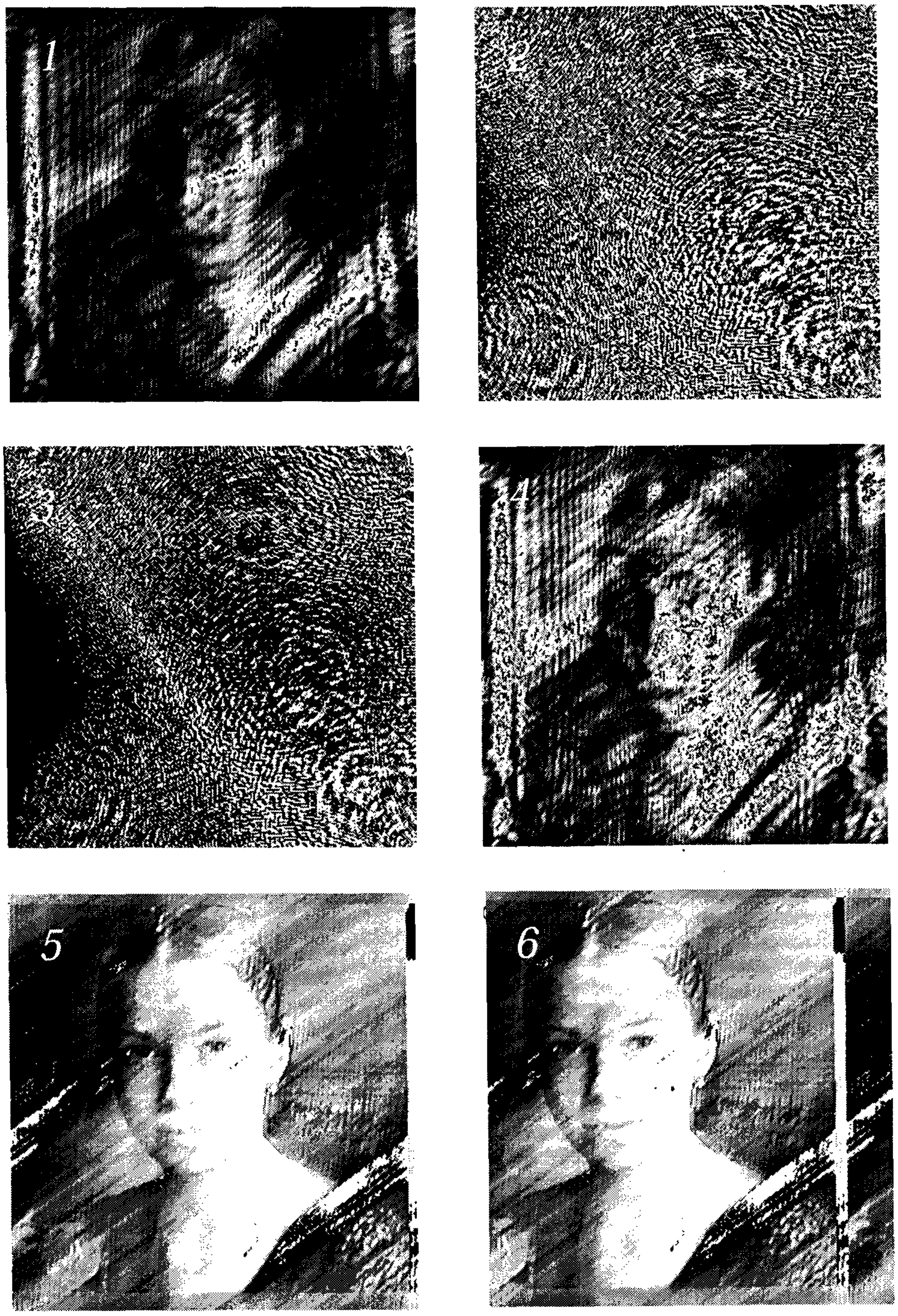

Figure4 . *Step-by-step bulk image reconstruction from acoustically created optical hologram. 1) electrical signals field; 2) Fourier transform of this field; 3) this Fourier-transform after coordinat transformation; 4) back Fourier transformation of field (3) - acoustically created dynamic optical hologram; 5)acousto-optical object image reconstruction from acoustically created dynamic optical hologram (at the moment of time exactly sinchronized to illumination pulse time); 6) this image, reconstructed at factor1.2 of illumination pulse duration period.*

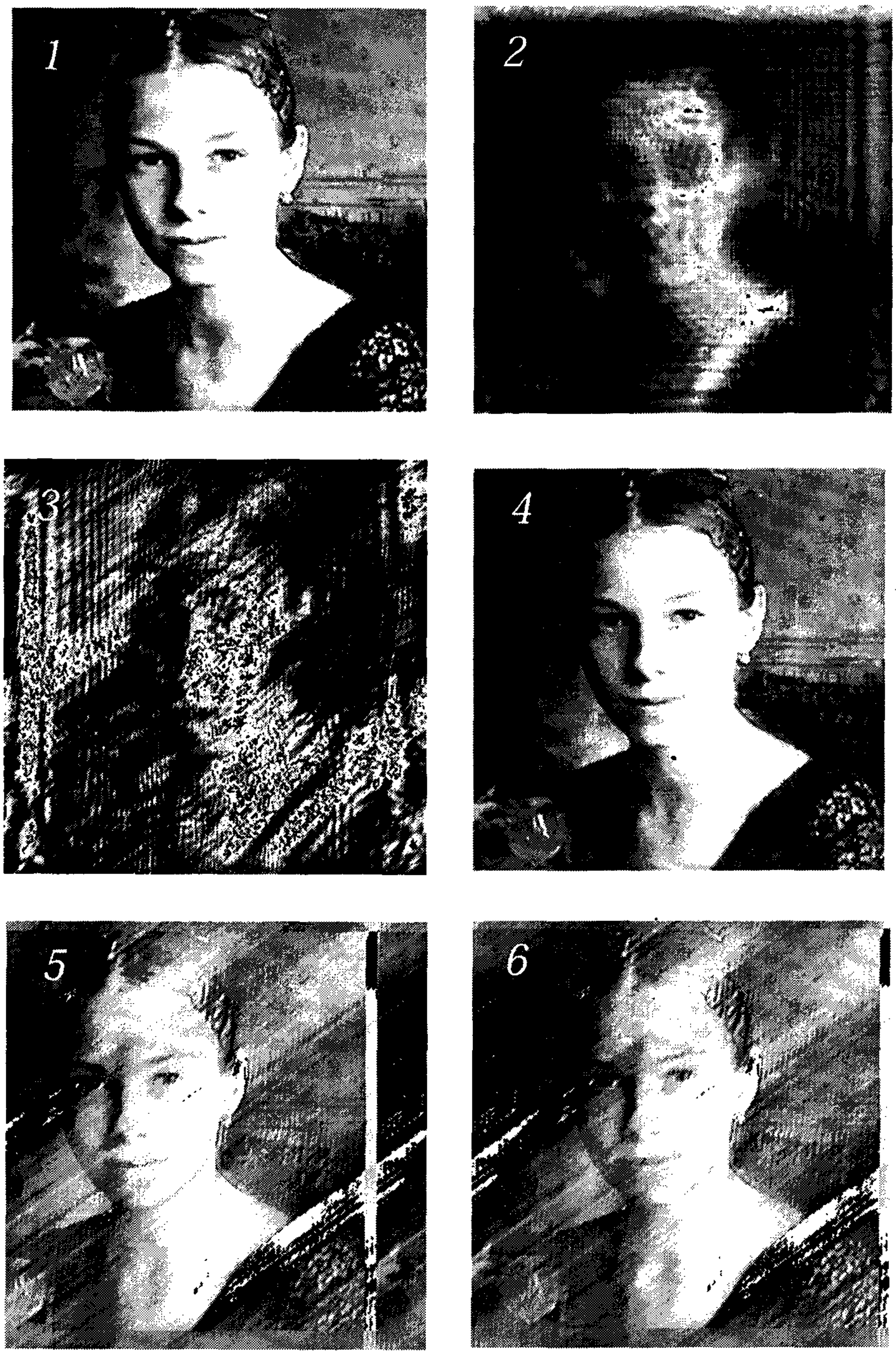

Figure 5 . Illustration of bulk image reconstruction from static optical and dynamic acoustically created optical holograms. 1) one plane of 3-D object image; 2) static optical hologram of this image; 3) dynamic acoustically created optical hologram; 4) object image, reconstructed from static optical hologram; 5) object image, reconstructed from acoustically created dynamic optical hologram at the time with factor 1.2 of illumination pulse period; 6) this image, reconstructed at the time exactly synchronized to illumination pulse.