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The Optimum Optical Geometry for Recording a Full Color Transmission type Holographic Screen of Large Size

Jai-Soon Kim*, V. I. Bobrinev, Jung-Young Son, Yong-Jin Choi, and Sang-Hun Shin

** Optechs-Korea company R/D Lab, Inchon 404-250, KOREA*
Korea Institute of Science and Technology, Seoul 136-791, KOREA

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The main problem of image projection on a transmission type holographic screen is color separation. And it can be overcome by using a long narrow slit type diffuser as a source of the object beam when we record the screen. But that screen is not optimized and so needs changing several conditions. To set up the system many complicate things should be taken into accounted so it is very important to analyze the basic structure by simple concepts and calculations. We designed the system so that recording and projection axis coincide in one line and showed that the analysis of the system is very simple. We did it by a 1st order paraxial approximation calculation and it was good enough to describe the system. The photo-emulsion layer shrinks after processing of the hologram. It induced unsatisfactory color matching at the viewing zone. To overcome this effect, we pre-checked the shrinkage rate of an emulsion layer by experiments and modified the recording set up to compensate for the amount of shrinkage.

I. INTRODUCTION

In the usual cases and our earlier papers, [1–4] the position of a projection lens aperture like P in Fig. 1 is not on the optical axis of a recording state. When the holographic screen has an image projected on it, the projected image is best focused when the normal to the screen center coincides with the optical axis of a projection lens system. But in that case the viewer's approaching angle to the center of a holographic screen should be large like α in Fig. 1. In many kinds of image projection system the optical axis of the projection system is not always normal to the screen. Similarly to an over-head-projector, tilting the screen several degrees does not significantly change its image performance. Distortion and defocusing are tolerable. So the projection lens aperture can be positioned on the same line connecting reference and diffuser source like P_O in Fig. 1 or P in Fig. 2(β is not normal to the screen).

If the two axis(recording and projecting reconstruction) are not coincident, it is not so simple a task to predict the proper diffuser position and its size, and calculation about its color contribution to the viewing zone is complicated. [1,4] But if the coordinate position of an image projection lens aperture is on the same line which was made by the reference source and diffuser, like Fig. 2, then the system analysis can be simplified to the first approximation to the on-axis case.

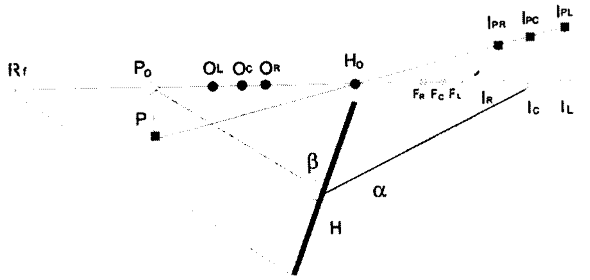


FIG. 1. General set up for recording full color transmission holographic screen, P: Projection lens, P_o: on axis position of P, R_f: Reference Source, H: Holographic screen, $I_R/I_C/I_L$: Images by O_L(long f)/O_B/(short f) projected at P_o on axis, $I_{PR}/I_{PC}/I_{PL}$: Images created by projection at P, $F_P/F_C/F_L$: Foci of H by R_f and $O_R/O_C/O_L$.
$*$ by dispersion I_R contributes blue/I_C green I_L red; near $I_{C'}$ position all spectral components are overlaid and the viewing zone is formed.

System setup by on axis analysis is simple but it can't derive an optimum condition. For a big screen, it is necessary to take into account that according to the Bragg law diffracted light brightness can not be the same for the different screen parts. Additionally the shrinkage of a photographic emulsion layer causes considerable change in the projected image. Therefore we should precompensate the recording system lay-out to

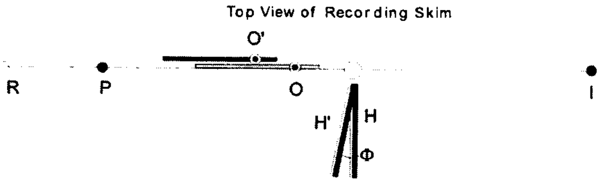


FIG. 2. On axis sep up for recording screen, R: Reference source, P; Projection Lens, I: Image of P(Viewing Zone), O: Base of diffusing Objective, O': Shifted O, H: Holographic Screen, H': Angle Φ rotated H.

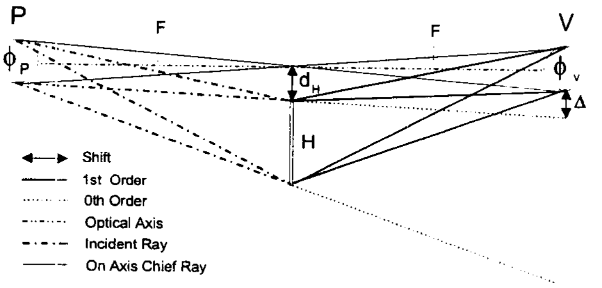


FIG. 3. Shifting Distance of a Hologram Screen from the Axis.

diminish the negative consequences of these effects. In this paper we found the optimum condition by changing the position of the diffusing object and the tilt angle of the holographic screen.

II. SET UP THE OPTIMUM RECORDING SYSTEM

II. A. On axis analysis by using in line projection lens system.

To setup the recording system on one axis by paraxial approximation, we set the reference source distance from photo-plate to be 200cm, and wanted viewing zone distance to be 150cm when the projection distance is 150cm. The viewing zone is the image of a projection lens aperture created by the holographic screen. Let us introduce the base object point on the diffuser, which contributes to the full colored viewing zone the same wavelength as that of the recording light. It becomes the basis of calculating the size of a diffuser. Here we don't need to calculate x-axis position [1] or angular position from the center of a hologram plate. [4] The target focal length f_H of our hologram can be calculated from projection distance Z_P and its image distance Z_I. [5,6]

$$\frac{1}{f_H} = \frac{1}{Z_P} + \frac{1}{Z_I} \tag{1}$$

To make a hologram of focal length f_H, the relation between reference source distance and object source distance can be written as

$$\frac{1}{f_H} = \frac{1}{Z_O(\lambda_0)} - \frac{1}{Z_R} \tag{2}$$

Where λ_0 means recording wavelength. Then we can find the base point of an object beam.

$$\frac{1}{Z_O(\lambda_0)} = \frac{1}{Z_P} + \frac{1}{Z_I} + \frac{1}{Z_R} \tag{3}$$

To get a full colored viewing zone we must consider the full spectrum range of the white light projected beam. The long narrow shaped diffusing object can mix all colored light together in one area of the viewing zone. [1] All other points on the diffuser correspond to a different spectrum and the relation can be written in the form [1,4,5]

$$Z_O(\lambda) = \frac{1}{\frac{1}{Z_R} + \frac{1}{\mu}(\frac{1}{Z_P} + \frac{1}{Z_I})} \tag{4}$$

where

$$\mu = \lambda/\lambda_0 \tag{5}$$

It is clear from Eq. (4) that a long narrow shaped diffusing object should be used in the screen recording set-up to mix all colored light together in one area of the viewing zone. [1] If we select 0.45μm and 0.65μm as blue and red wavelength λ, the diffuser length D and position can be calculated

$$\begin{aligned} D &= Z_O(\lambda = 0.65) - Z_O(\lambda = 0.45) \\ &= 666\text{mm} - 514\text{mm} = 152\text{mm} \end{aligned} \tag{6}$$

We must record the hologram at a vertical site to prevent the 0th order diffraction beam from entering the viewing zone when we project a full colored image on the holographic screen. The proper shifting distance d_H can be derived easily from Fig. 3.

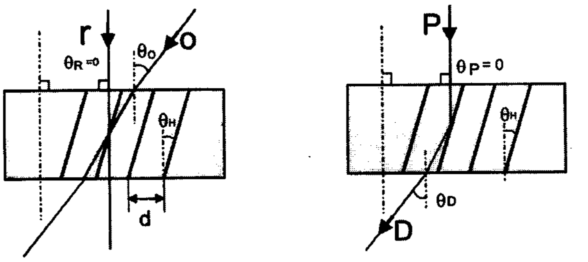
In our system the projection magnification is 1, so if the diameter of the projection lens aperture Φ_P is 28mm then the size of the viewing zone that is an image of the projection lens is also 28mm. The 0th order beam should not enter into the viewing zone and we need some extra distance Δ. If we choose Δ = 40mm, the shifting distance is as follows.

$$d_H = \frac{\Phi_P + \Delta}{2} = 34\text{mm} \tag{7}$$

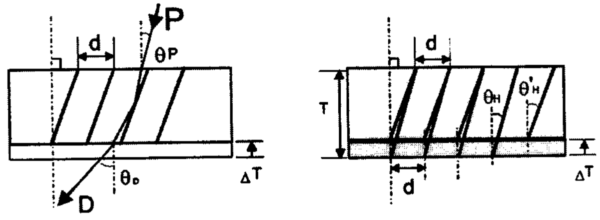
We fixed d_H as 40mm in our experiment for the convenience.

II. B. Shrinkage of a photo-emulsion layer changes bragg condition.

Some problems arise in color correction at the view-



(A) Recording Setup (B) Reconstruction without Shrinkage



(C) Reconstruction with Shrinkage (D) Compare the Slanted Angle

FIG. 4. Shrinkage of a Photo-Emulsion Layer, R/θ_R: Recording reference ray and its input angle, O/θ_o: Recording objective ray and its input angle, P/θ_p: Reconstructng projection ray and its input angle, D/θ_d: Reconstructed (diffracted) ray and its direction, $T/\Delta T$: Original and shrunken thickness of photo-emulsion layer, θ_h: Slant angle of diffraction pattern, d: Inter fringe distance.

ing zone of the holographic screen which was recorded by the on line setup. In particular, the marginal bottom field of the projected image showed unsatisfactory color reproduction. It was because of the changes in the orientation and spacing of the fringe patterns inside a hologram due to the shrinkage of a photo-emulsion layer. [6]

To quantify the shrinkage rate we made several small sample holograms by using a He-Ne laser and giving some deviation angle(40°) relative to the object beam from the reference beam(normal to the emulsion layer). By checking the variation angle of the Bragg condition according to the shrinkage effect as in Fig. 4, we can calculate the shrinkage rate of a photo-emulsion layer.

The interfringe distance "d" and the slant angle of diffraction patterns "θ_H" at the recording state without shrinkage can be derived from the diffraction condition equation written in the form

$$d(\sin\theta_{O,D} - \sin\theta_{R,P}) = \lambda_R \tag{8}$$

$$d = \frac{\lambda_R}{\sin\theta_{O,D} - \sin\theta_{R,P}} \tag{9}$$

$$\theta_H = \frac{\sin^{-1}(\frac{\sin\theta_P}{n_H}) + \sin^{-1}(\frac{\sin\theta_D}{n_H})}{2} \tag{10}$$

After shrinkage of d, λ_R is the same and maximum diffraction input angle varies from θ_P to θ'_P. Then from Eq. (9)

$$\theta'_D = \sin^{-1}(\frac{\lambda_R}{d} + \sin\theta'_P) \tag{11}$$

After substituting θ'_P and θ'_D into Eq. (10), we can calculate the changed slant angle θ'_H and then the shrinkage rate s can be written as

$$s = 1 - \frac{\tan\theta'_H}{\tan\theta_H} \tag{12}$$

At the recording stage the reference beam is incident normal and the object beam is at 40° to the holographic screen. After processing of the holographic plate the best diffraction efficiency in the reconstruction beam was obtained if the input beam incidence angle was changed by 8°. From that angle variation we can determine the shrinkage rate of the photo-emulsion layer to be approximately 32%. Here we use 1.52 as the optical index of the emulsion layer and 0.635μm as the wavelength of laser.

II. C. Compensating condition for shrinkage effect.

The shrinkage effect has an especially important influence at the far edge of a holographic screen, because interference patterns that have a steep slope are made at that screen region by the effect of the near point diffuser plate from the screen. So the angle variation of the fringe patterns and of the Bragg condition effect are relatively bigger than for the other screen region.

From the recording setup of Fig. 2, we can calculate incident angles, diffraction angle, inter-fringe distance and slant angle of fringe patterns. Its detailed drawing is shown in Fig. 5. Here we consider the on-axis setup, where the photo-plate surface is perpendicular to the axis reference beam source-diffuser. From the calculation of Eq. (6), we choose the nearest diffuser distance as 500mm (use little longer size diffuser) and use a 0.488μm Ar laser as a recording beam. Then by Eq. (9) and (10) we can get

$$\begin{aligned} d &= \frac{0.488}{\sin[\tan^{-1}(\frac{34}{50})] - \sin[\tan^{-1}(\frac{34}{200})]} \\ &= 1.24 \end{aligned} \tag{13}$$

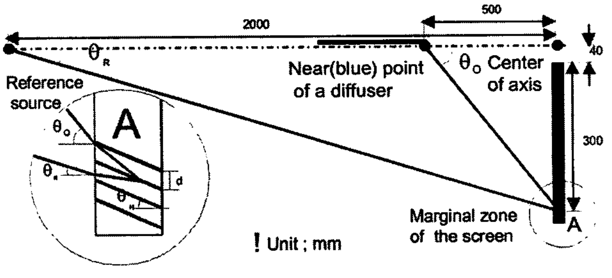


FIG. 5. Fringe pattern at the recording state.

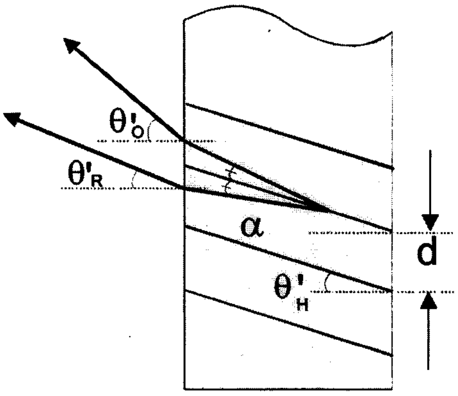


FIG. 6. Recording condition for compensating shrinkage.

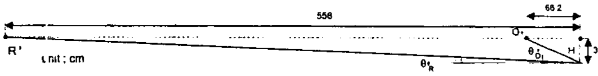


FIG. 7. Preliminary setup for compensating shrinkage.

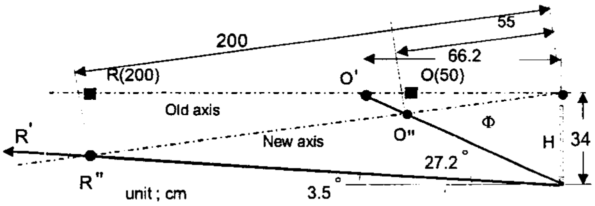


FIG. 8. Optimum condition modified from Fig. 7.

$$\theta_H = \frac{\sin^{-1}[\frac{\sin\{\tan^{-1}(\frac{34}{50})\}}{1.52}] + \sin^{-1}[\frac{\sin\{\tan^{-1}(\frac{34}{200})\}}{1.52}]}{2}$$
$$= 14 \tag{14}$$

We hope the same shaped fringe structure will be created after the shrinkage process. To do that, some modification of the recording system is needed. The position of a diffusing object and the normal direction of the holographic screen will be changed to optimum conditions according to the first order approximation analysis.

Inter fringe distance $d = 1.23\mu$m remains constant but the slant angle of diffraction fringes will be changed to a bigger value after shrinkage so we must pre-reduce that angle θ'_H. We assume the shrinkage rate to be 30% and s=0.3, by Eq. (12). Therefore we can write θ'_H

$$\theta'_H = \tan^{-1}(0.7\tan 14°) = 9.9 \tag{15}$$

So to fulfill those conditions we must change the positions of reference and diffusing object source to modify the input angles θ_O and θ_R. If we express the varied angle with '(as like as from a to a') the system looks like Fig. 6.

From Eqs. (8) and (9) we can derive following simultaneous equations.

$$1.23 = \frac{0.488}{\sin\theta'_O - \sin\theta'_R} \tag{16}$$

$$9.9 = \frac{\sin^{-1}(\frac{\sin\theta'_R}{1.52}) + \sin^{-1}(\frac{\sin\theta'_O}{1.52})}{2} \tag{17}$$

We can find θ'_R and θ'_O by numerical approximation. Let us designate by α the angle inside the emulsion between the fringes and the interfering beams, as shown in Fig. 6. Then we can write

$$\theta'_O = \sin^{-1}[1.52\sin(9.9° + \alpha)]$$
$$\theta'_R = \sin^{-1}[1.52\sin(9.9° - \alpha)] \tag{18}$$

The solutions are, $\theta'_O = 27.2°$, $\theta'_R = 3.5°$ when $\alpha = 7.6°$.

So we should change the reference and object positions according to these angles. But in this case the reference source distance is too far from the holographic screen as in Fig. 7. So we should turn the optical axis properly as in Fig. 8 and it has the same meaning as turning the screen. Here we fix the reference source(R'' in Fig. 8) distance from the holographic screen as 200cm. In that case the rotation angle ψ which is the same angle Φ as in Fig. 2 is 6.2°. And the distance to O'' is written as follows

$$d_{O''} = \frac{66.2 \times \tan 27.2}{\sin 6.2 + (\cos 6.2)\cdot(\tan 27.2)} = 55 \tag{19}$$

So the diffusing object should be moved back on the axis about 5cm.

FIG. 9. Image which was projected on the manufactured holographic screen was captured by digital camera at the single viewing zone.

III. RESULTS OF EXPERIMENT

The transmittance holographic screen of 30cm × 40cm size has been manufactured by using the setup of Fig. 8. The diffused object beam intensity at the near edges(to the axis) of the screen is weaker than at the center zone of it. When we projected an image on that holographic screen at the 1-magnification system (distance of the projector is same as its image distance) the total system conjugate distance showing the best image quality is little shorter than expected value which was analyzed by 1st order paraxial approximation. It means that more detailed analysis is necessary to take into account all volume hologram effects induced especially at the marginal area of the screen.

The projected stereoscopic image shows high resolution, good image depth and good color correction. The picture of its real image which was seen by only one eye was presented in Fig. 9. The background color noise, which causes image quality deterioration, is induced by the stray light in the holographic screen recording setup.

IV. CONCLUSION

To record the bigger size transmittance holographic screen that can have a good projected image, we must analyze the detailed internal function of the recording process more precisely.

We will be able to change experimently several factors such as objective diffusers shape(size) and position combined with the position of a reference beam source, emulsion layers tilt angle, invention of uniform illumination method of diffusing beam, bragg condition modification to calibrate the photo layers shrinkage effect. More detailed analysis of the chromatic(dispersion) aberration induced by the diffraction patterns created at the marginal zone of the holographic screen is necessary for further screen improvement.

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