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Comparative Studies of Holographic and Speckle Interferometry for Two Identical Diffusers

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ABSTRACT. The characteristics of interference pattern for single and double interference holograms were compared to those of two separate identical diffusers. Several advantages over the system of two parallel identical diffusers were found.

Holography is an interferometric method of recording light waves scattered from an object which is illuminated by spatially and temporally coherent beams. The scattered waves have to interfere with a definite reference wave. If the waves have a high degree of coherence, the relative phase between the object and reference waves remains constant in time so that an interference pattern may be observed. This interferogram, if recorded photographically, is called a hologram. The hologram contains information about both the phase and the amplitude of the light scattered from the object. In this way, the phase information can be transformed into an intensity distribution by use of the reference wave.

Speckle patterns, which are photographically recorded, play the role of amplitude objects of random structure and enable light to be scattered giving rise to a continuous spectrum in the Fourier spectral plane. Under certain experimental conditions interferograms may be produced in this Fourier plane.

Burch (1953) was the first to show how interference with scattered light may be applied to interferometry. Two identical diffusers (TID) are placed side by side in the plane containing the centre of curvature of the concave mirror under test and perpendicular to its optical axis. Interferograms showed the profile of the mirror surface in terms of the deformation of the fringes. Pontiggia and Zefiro

(1974) described an interferometric experiment with two identical diffusers in contact. They related the phase difference with the refractive index of the film substrate. A comparison of their formulae with experimental measurements gave an agreement within 5%. Barakat *et al.* (1982) studied the path diffference between TID in terms of the separation between them, their refractive index, their substrate thickness and the incident wavelength. They derived a new formula and made an experimental verification with an error of 2.5%. Francon (1979) studied the conditions for producing circular interference fringes with single and multi-exposure using speckles from an amplitude diffuser.

The aim of the work in this article is to study and apply experimentally the general principles of circular fringes produced from interference holograms. Single and double-exposure holograms are prepared using an amplitude diffuser. Comparison of the results of interference holograms with those of two identical diffusers is considered.

Diffuse Object

The scattering plates, or diffusers, which are used in the experiments are obtained in the form of speckle patterns (Francon 1979). The speckles were recorded when $\lambda = 0.6\ \mu m$ and $\alpha = 1/10$, so that the grains had diameters of the order of $6\ \mu m$. High resolution photographic plates of the type Agfa Gevart 10 E 75 or the type Kodak 649 F were used to record speckle pattern so that they served as excellent diffusers.

Circular Interference Fringes of Single Exposure Hologram

We discuss here how circular interference fringes similar to those of two identical parallel diffusers can be produced making use of holography. A single exposure interference hologram is obtained by using the set-up previously described by Francon (1975, 1979). Illuminating the hologram H by a parallel beam of light, two identical and symmetrical diffusers are reconstructed as shown in Fig. 1-a; in the form of virtual image D″ and a real image D′. In this case, the two emulsions are facing each other. These two images produce circular fringes localized at infinity due to interference with a phase difference $\delta\varphi$ given by

$$\delta\varphi = \frac{\pi}{\lambda} \cdot \frac{R_k}{f^2} \cdot 2L \tag{1}$$

since D′ and D″ are separated by 2L and R_k is the radius of the fringe of order K. For bright fringes $\delta\varphi = 2\pi k$, consequently for two successive bright fringes we get

$$R_{K+1}^2 - R_K^2 = \frac{\lambda f^2}{L} \tag{2}$$

which is the same formula as for two identical diffusers (Barakat *et al.* 1982) when the thickness of the diffusers is not included in the optical path.

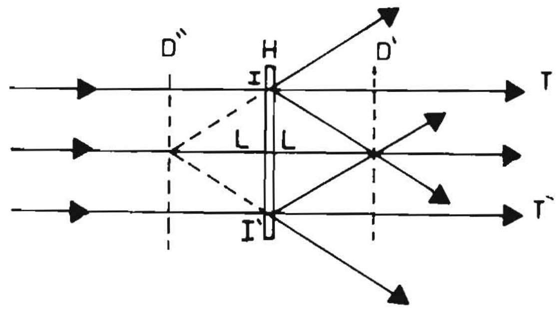

Fig. 1-a. Reconstruction of images D′ and D″ of the diffuser D from the hologram H.

Circular Interference Fringes of Double-Exposure Hologram

According to Eq. (1), the rings become more crowded, when increasing the distance L. In order to get rid of this difficulty, a double-exposure hologram may be used. In this case, interference takes place either with two virtual images or with two real images whose separation, Z, may be so small that rings with large diameter can be produced. The performance of the double-exposure hologram is given by Francon (1979). The photographic plate, H, is to be axially translated along the Z-axis for a very small displacement (a few microns) between the two exposures.

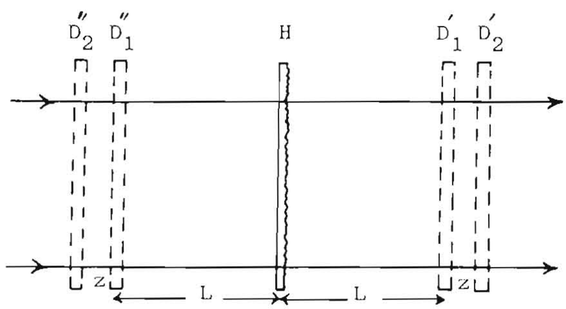

Fig. 1-b. Reconstruction of the four images D_1', D_2', D_1'' and D_2'' of the diffuser D from the doubly-exposed hologram H.

Illuminating the hologram by a parallel beam, four images are reconstructed; two real images D_1' and D_2', and two virtual images D_1'' and D_2'' as shown in Fig. 1-b. To observe interference fringes, a converging lens is used to collect parallel light beams in the focal plane from each pair of reconstructed images. These rings have big diameter since the separation of images in each pair is relatively small. This system of rings is of special concern rather than the ring system due to widely separated images.

Sharpening of the rings may occur if a multi-exposure technique is adopted. The photographic plate is displaced through a fixed distance between two successive exposures. In this case, N exposures are made. The rings have an intensity distribution given by Francon (1979).

$$I = I_0 \left\{ \frac{\mathrm{Sin}(N\pi Zi^2/2\lambda)}{\mathrm{Sin}(\pi Zi^2/2\lambda)} \right\}^2 \qquad (3)$$

According to this equation, the greater the number N, the sharper the fringes to be obtained. However, there is a limit which is set by the dynamic range of the photographic emulsion.

Data Reduction in the Case of Single Exposure

If a single-exposure interference hologram is used to produce circular interference fringes, two reconstructed images can be obtained. These images can be treated as two identical diffusers separated by a distance 2L. The phase difference for each bright fringe is given by Eq. (1). Some of the obtained interference patterns are shown in Plate 1. If the squared radii R_K^2 of the fringes are related to the

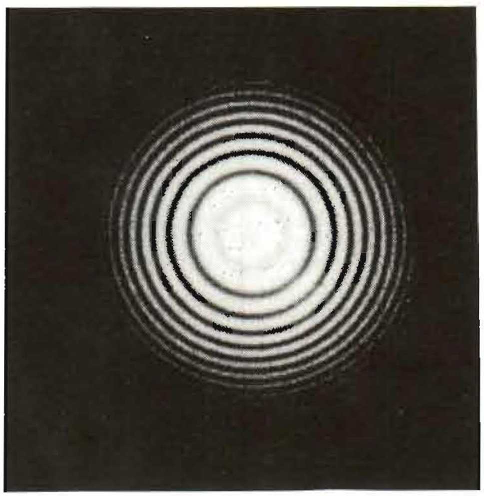

Plate 1. Fringes from single exposure hologram of separation 7 mm at λ 6328 Å.

order of appearance K, straight lines are obtained for the wavelengths 6328 Å, 5780 Å, 5461 Å and 4358 Å, *e.g.* as shown in Fig. 2. According to Eq. (1), for each wavelength, as the separation L increases, the slopes of the straight lines decrease. From these straight lines one can deduce the wavelength from their slopes, which is equal to $\lambda f^2/L$, if the focal length f of the lens is known (f = 58 mm). The used wavelengths are calculated from the slopes of the straight lines. For the red line of the He-Ne laser (Fig. 2), an error of 1.0% was estimated. Also from these curves the separation, L, was calculated and the obtained values had an error of 4.1% in comparison with the mechanically measured values. Meanwhile, the focal length is measured from Fig. 2 with an experimental error of 1.6%.

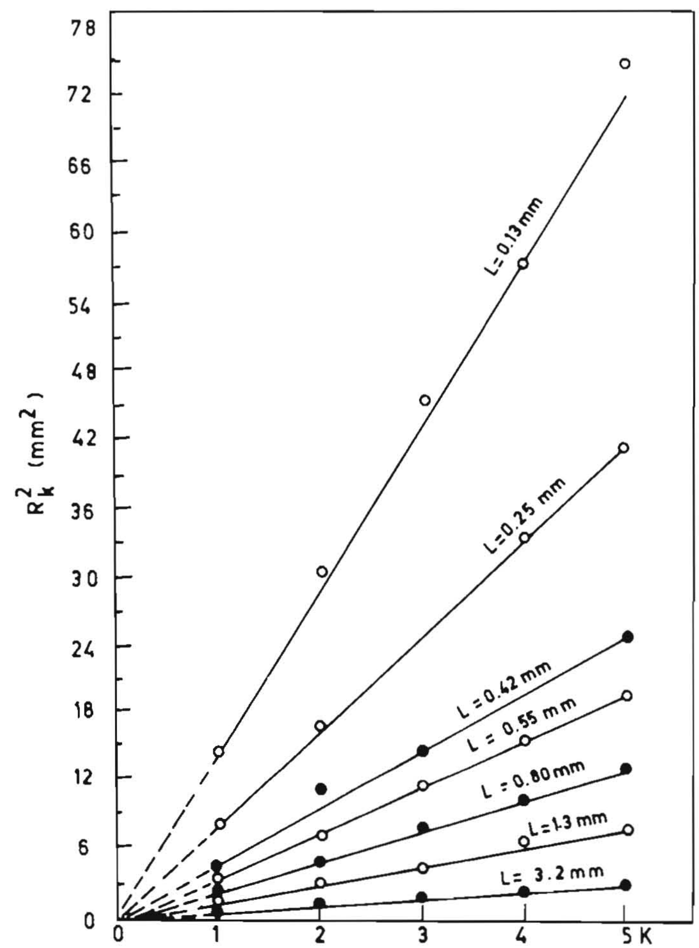

Fig. 2. Relation between the squared radii of the fringes and their order of interference, for λ = 6328 Å.

Relating the difference of squared radii of the fringes to the wavelength of the used light for different separations (L = 0.25, 0.55 and 0.80 mm), another set of straight lines is obtained. The extrapolation of these straight lines meet in the origin as shown in Fig. 3. From Eq. (2), the slopes of these straight lines are given by f^2/L, where f is the focal length of the used lens. Accordingly, the slope of every straight line increases as the separation, L, decreases. Figure 4 represents the relation between the reciprocal of the separation L, and the difference of squared radii for different wavelengths (λ = 6328 Å, 5780 Å, 5461 Å and 4358 Å). This family of straight lines intersect in the origin. They have different slopes which are equal to

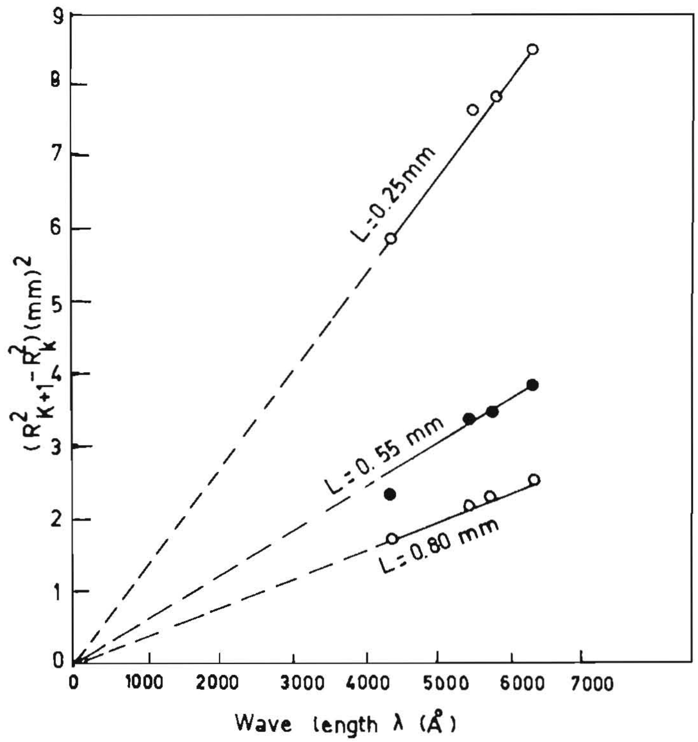

Fig. 3. Relation between the difference of radii squared and the wavelength of the incident light.

Table 1. The measured wavelengths in comparison with the applied wavelengths.

Wavelength of the standard source	(nm)	632.8	578	546.1	435.8
Measured wavelength	(nm)	629.4	585.6	547.9	442.9

λf^2. It is clear that their slopes decrease as the wavelength decreases. The used wavelengths are calculated from the slopes of straight lines with an experimental errors 0.6, 1.3, 0.4 and 1.6% for the wavelengths, respectively. Table 1 shows the measured wavelengths that deduced from Fig. 4 and that applied experimentally fron. the standard spectral lamps.

The fractional orders for each system of the obtained fringes are calculated using the least-square method and is found to be in the range from 0.98 to 1.02. This means that the center of rings is usually bright. Moreover, the last-square fits are successfully applied to Fig. 2-4, and the calculated standard deviation for the focal length is 0.88 mm, while for the separation ranges from 0.012 mm to 0.08 mm, and for the wavelengths ranges from 9 Å to 60 Å.

Data Reduction in the Case of Double Exposure

At a separation of 18 mm between the diffuser D and the hologram H, two exposures were recorded on H with a small axial translation Z. Four holograms were

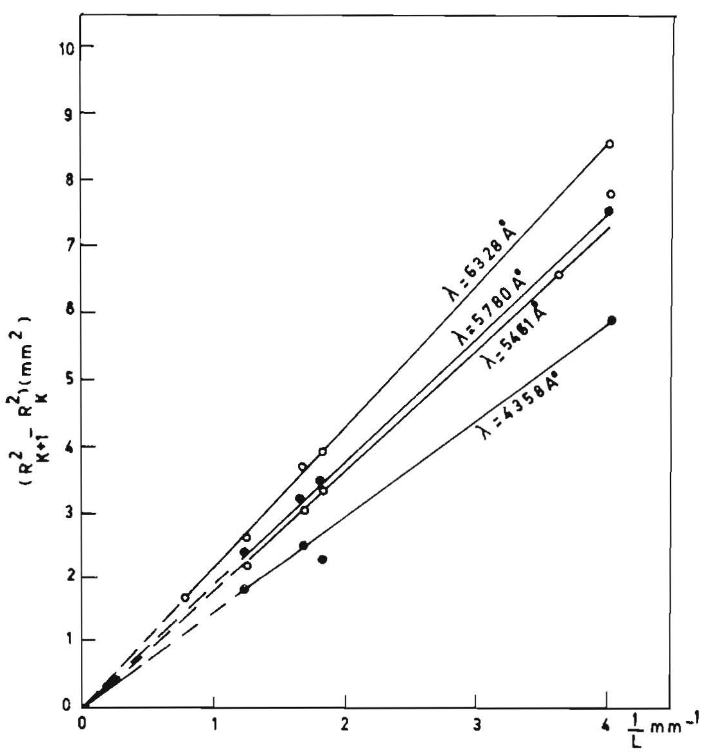

Fig. 4. Relation between the reciprocal of separation L and the difference of radii squared.

produced with different axial translations Z = 10, 30, 50 and 80 μm. A He-Ne laser (λ = 6328 Å) was used in order to form interference fringes as shown in Plate 2. Relating the axial translation Z to the radius of a given fixed ring (say the first order), a straight line with negative slope is obtained as in Fig. 5. This curve is also least-square fits. Moreover, an increase of the axial translation, Z, decreases the radius of the fringes as shown in Fig. 5.

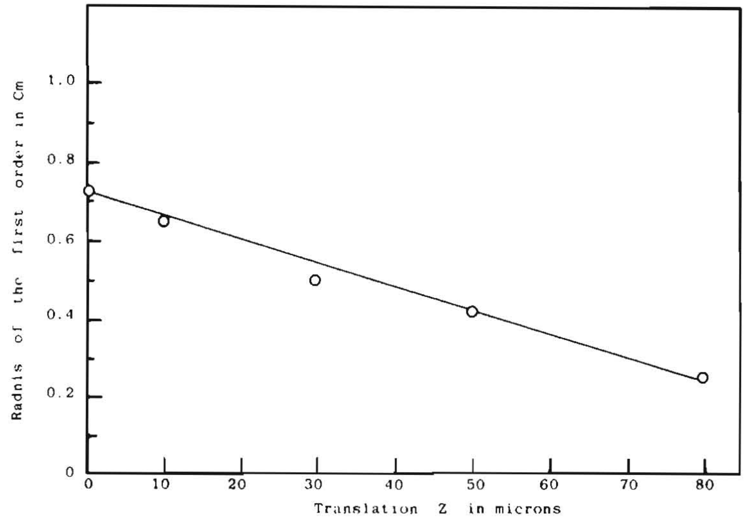

Fig. 5. Relation between the axial translation Z and the radius of certain fringe order R_K (K = 1).

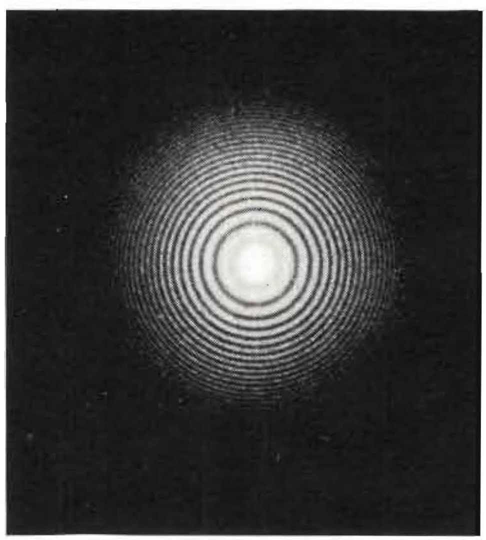

Plate 2. Interferogram of double-exposure with axial translation 80 μm.

Advantages of an Interference Hologram

Making a comparison between the experimental results of TID and those of an interference hologram, one can find agreement between the applied formula and different relations for separations and wavelengths. Also the accuracy of an interference hologram is 2.5%; the same as that for TID.

Moreover, other advantages of using an interference hologram over the system of two identical diffusers are:

1) In the case of an interference hologram, the interference results from a single optical piece, while the same pattern is produced from TID with difficulties in arrangement.

2) With an interference hologram, there is no need for critical adjustment as in the case of TID; a special jig is used to achieve the adjustment.

3) The interference gap of the hologram with a maximum value 36 mm, is twice that of the two identical diffusers.

4) The thickness of the diffusers is not included in the phase difference of the interference beams because the two images of emulsion are facing each other.

5) The photographic processes are carried out only on one plate with interference hologram.

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دراسات مقارنة عن تصوير التداخل المجسم و العشوائى لمشتتين متماثلين

توفيق الدسوقى و حاتم الغندور
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بدراسة خصائص نموذج التداخل للمجسمات المنفردة و المزدوجة ومقارنتها بهدب التداخل الناتجة عن مشتتين متماثلين منفصلين، أمكن الكشف عن المميزات العديدة التى يتفوق بها تداخل التصوير المجسم عن مثيله.