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The effects of density and bleach concentration on efficiency and resolution in phase holograms

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THE EFFECTS OF DENSITY AND BLEACH CONCENTRATION ON EFFICIENCY AND RESOLUTION IN PHASE HOLOGRAMS

by

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LIST OF NOMENCLATURE

Noise- the amount of flux, upon reconstruction, from an area which contained no flux at exposure.

Reconstruction Ratio (R)- the ratio of the amount of light in a holographic image of an object to the light in the image of the object itself, both images being formed with the same optical system.

ABSTRACT

An experiment was run to quantitatively define the effects of density and bleach concentration on noise, resolution, and reconstruction ratio for phase holograms. Results showed bleach concentration has no significant effect on the response variables, while density shows a quadratic increase in reconstruction ratio and noise with no effect upon resolution.

INTRODUCTION

Since 1963, there has been a dramatic increase in research and applications of holography. Although much has been published, some specific parameters concerning holographic imaging have not been quantitatively examined. Much investigation has been done with regard to the optics and physics of holography, however, the quality of the holographic image is fundamentally dependent upon the photographic recording medium and its related processing parameters. Work done by Leonard and Upatnieks[1], for example, has shown that the quality of the holographic image varies with different bleaching techniques. McMahon and Franklin[2] have demonstrated that optical quality also depends on the developed density of the silver halide emulsion. Little has been published however, concerning the correlation of the various processing parameters and their quantitative effects upon the holographic image.

This thesis is concerned with the effects of developed density and bleach concentration on noise,resolution and reconstruction ratio of the holographic image. Bleaching the silver halide emulsion results in a phase hologram which is capable of greater diffraction efficiency than unbleached, amplitude holograms. It is important to note that optical path variations associated with a bleached hologram are caused

Are these opposed or reinforcing?

by a relief image, due to a tanning bleach, and an index change(the variation of the refractive index of the emulsion layer)[3]. Both concentration of the tanning bleach and the pre-bleached density affect the height of the relief image and ultimately, diffraction. Work done by Altman[4] shows a linear relationship between density and the relief height for Kodak 649-F plates. Likewise, Lamberts[5] has found that changing the concentration of Kodak R-10 bleach (a tanning bleach), and bleaching 649-F plates, produces a significant change in the height of the relief image.

It is known that as density of the pre-bleached emulsion is increased, the result is an increase in diffraction efficiency[6]. Associated with this increase in diffraction efficiency is a corresponding increase in noise(scattered light from the emulsion). The effect that this noise increase has upon resolution is not fully known. The purpose of this analysis, therefore, is to quantitatively define how bleach concentration and density affect the holographic image with respect to noise, resolution and reconstruction ratio.

EXPERIMENTAL PROCEDURE

The film chosen for this analysis was Eastman Kodak High Speed Holographic Film(prototype of Kodak SO-253). Its relatively high speed(approximately 100X faster than 649-F materials)[7] and spectral sensitivity were well suited for the 3.0 mW Helium-Neon laser source used in this particular holographic system. The emulsion thickness is 9 micrometers and is coated on a 100 micrometer clear polyester base. Holographic exposures on this film were processed in Kodak Developer D-19, which is the recommended developer for this emulsion. D-19 has been used widely in the past as a holographic developer due to its ability to yield high speed and contrast from holographic films.

Since this investigation involves phase holograms, a suitable bleach was needed to yield high diffraction efficiency. Kodak R-10 Bleach was chosen and the formula is as follows:

Kodak R-10 Bleach

<u>Stock Solution A</u>

Distilled water	500 ml
Ammonium Bichromate	20 g
Concentrated Sulfuric Acid	14 ml
Distilled water to make	1 liter

<u>Stock Solution B</u>

Sodium Chloride	45 g
Distilled water to make	1 liter

Dilutions Used:
a) 1 part A, 1 part B,10 parts distilled water.
b) 1 part A, 1 part B,20 parts distilled water.
c) 1 part A, 1 part B, 5 parts distilled water.

The R-10 formulation was used in the three dilutions listed on the previous page in order to determine the quantitative effects upon noise, resolution and reconstruction ratio when bleach concentration is varied. Holograms that were developed, fixed and washed were bleached in one of the three bleach concentrations for 3 minutes using continuous tray rock agitation.

The second parameter under investigation was the pre-bleached density of the hologram. Preliminary sensitometric analysis of the film showed that a large density range of constant slope existed. It is important that exposures be made on this portion of the characteristic curve in order to keep harmonic distortion of the incident wavefront constant. The mean pre-bleached densities were achieved by varying the exposure time and keeping the development time constant. Density levels chosen were net densities of 0.73, 2.22 and 4.48 briggs(diffuse density). It is important to note that these were average densities, since an actual fringe pattern is made up of varying density values.

The processing sequence for each exposed hologram was as follows:

Process Step	Solution Used	Time
Development	D-19	5 min.
Stop Bath	Distilled Water	30 sec.
Fixer	Kodak F-6	5 min.
Wash	Tap Water	5 min.
Bleach	R-10(a, b or c)	3 min.
Wash	Tap Water	20 min.
Dry @ room temperature		

The agitation method used during development, stop and fix was ANSI standard tray rock. Continuous tray rock was used during bleaching.

This experiment was statistically designed and conducted in a 3^2, twice replicated, crossed factorial design(see appendix).

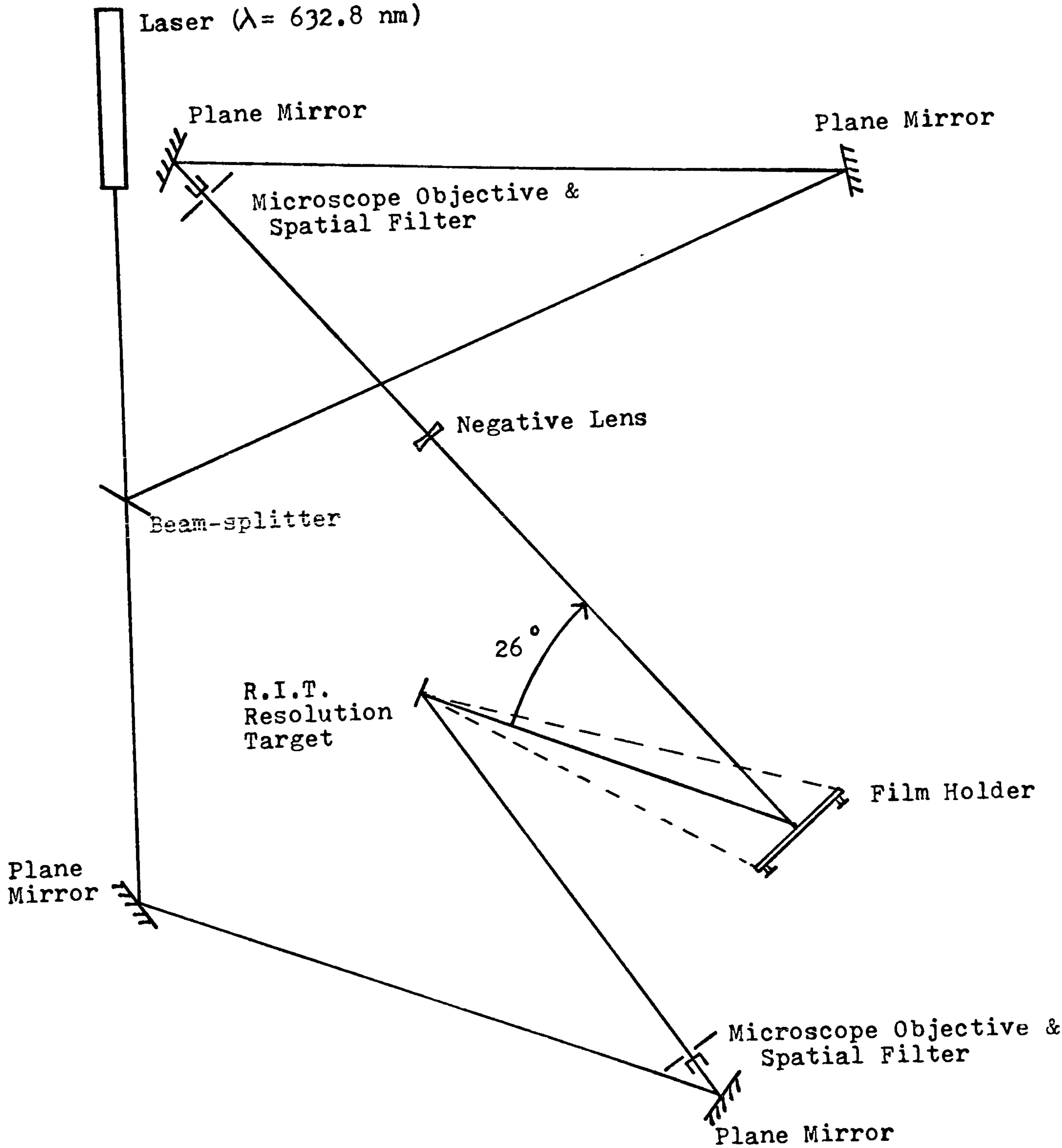
EXPERIMENTAL APPARATUS

The holographic system used in this analysis is illustrated in Figure 1 . An off-axis hologram is made of an R.I.T. Alphanumeric Resolution Target RT-1-71 , which has an adjacent white path area that is used for measuring reconstruction ratio. The angle between the object and reference beams is 26 degrees and this yields a mean fringe frequency of 710 cycles/mm at the film plane. This particular angle was chosen because it is convenient to make off-axis holograms at acute angles near 30 degrees so that non-uniform illumination does not become a problem. In addition, if the angle between the object and reference beams exceeds 56 degrees, the resolving power capability of the film type becomes an important factor. The film used in this experiment has a resolving power of approximately 1500 cycles/mm and exceeding 56 degrees between the object and reference beams will no longer yield a hologram.

The size of the hologram being formed was 7.62 X 7.62 cm and the negative lens, located in the reference beam was

FIGURE 1

HOLOGRAPHIC SYSTEM



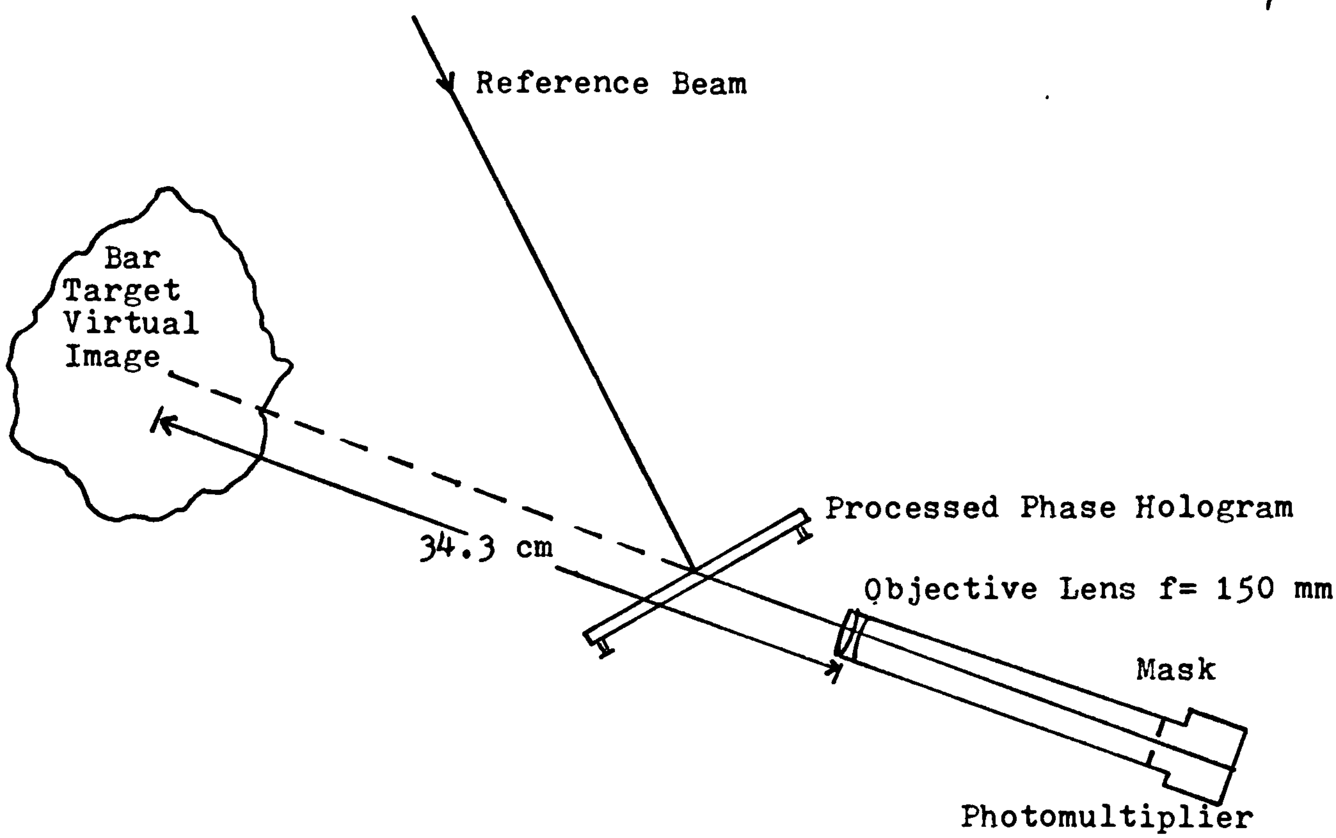


FIGURE 2 APPARATUS FOR MEASURING RECONSTRUCTION RATIO

used to promote even illumination over this 7.62 X 7.62 cm area.

The reference to object beam ratio was 116:1 and this high value was chosen to avoid a halo effect that is caused by multiple reflections at small beam ratios. At a beam ratio of 116:1 , the modulation of the fringe pattern is 0.18 .[8]

MEASURING APPARATUS

The measurement of reconstruction ratio R,(the ratio of the amount of light in a holographic image of an object to the light in the object itself)[9] is illustrated in Figure 2 . This is accomplished by imaging the reconstructed image of the bar target (with a 150 mm focal length lens) onto a circular mask (diameter= 4 mm). The mask permits only a selected portion of light from the white patch to pass. The flux passing through this mask is incident on a photomultiplier tube and the ratio of the flux from the holographic image to the flux measured from the original target is defined as the reconstruction ratio, R . The object distance was 34.3 cm and this accounted for flux from an area of 21 mm^2(in the object) to be incident on the photomultiplier.

The parameter called reconstruction ratio that is described above, is related to a more common expression, diffraction efficiency, by the following equation[10]:

$$R = k \times (\text{Diffraction Efficiency})$$

- where k is the beam ratio.

Noise in a holographic image is caused by emulsion scatter[11] and is difficult to measure because it depends on the collecting aperture of the radiometer and from what part of the image the scattered flux is collected. Therefore, only a relative measure of noise was determined in this experiment. For this analysis, noise is defined as the amount of flux,upon reconstruction, from an area which contained no flux at exposure.

Noise was measured with the spot reading photomultiplier described previously in this section and with the same collecting aperture as used for the reconstruction

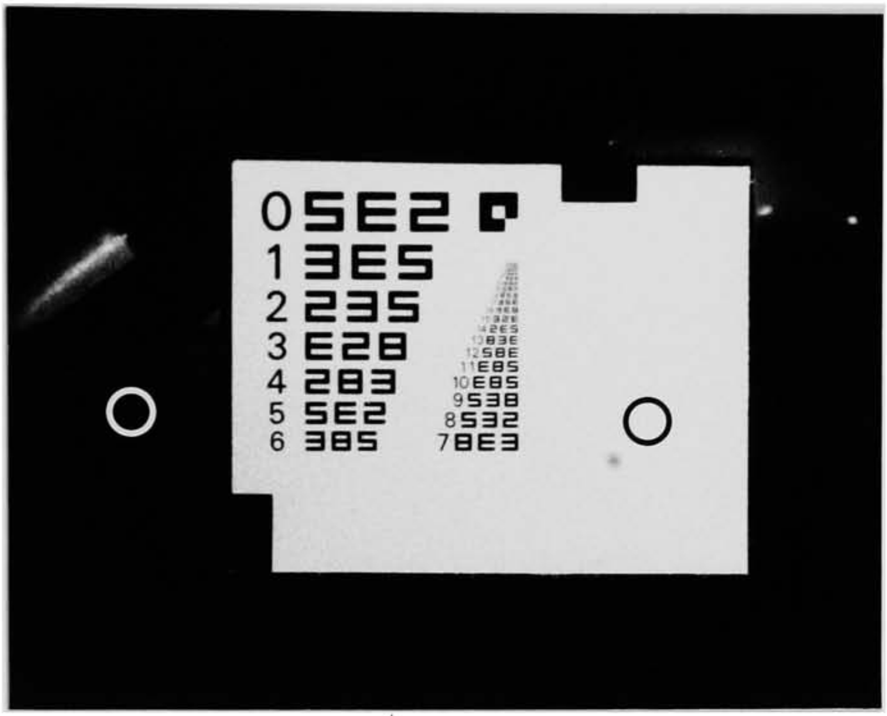


FIGURE 3 R.I.T. RESOLUTION TARGET, Circles indicate areas used for flux measurements to determine noise and reconstruction ratio.

ratio determinations. Figure 3 illustrates the two areas from which reconstruction ratio and noise were determined. The white circle indicates the area where there was no flux during the exposure. The flux measured from this spot, upon reconstruction, was used to determine the value of relative noise. The black circle indicates the area from which reconstruction ratio was determined. A flux measurement was made in this area before exposure and upon reconstruction. These two measurements determine the reconstruction ratio previously described.

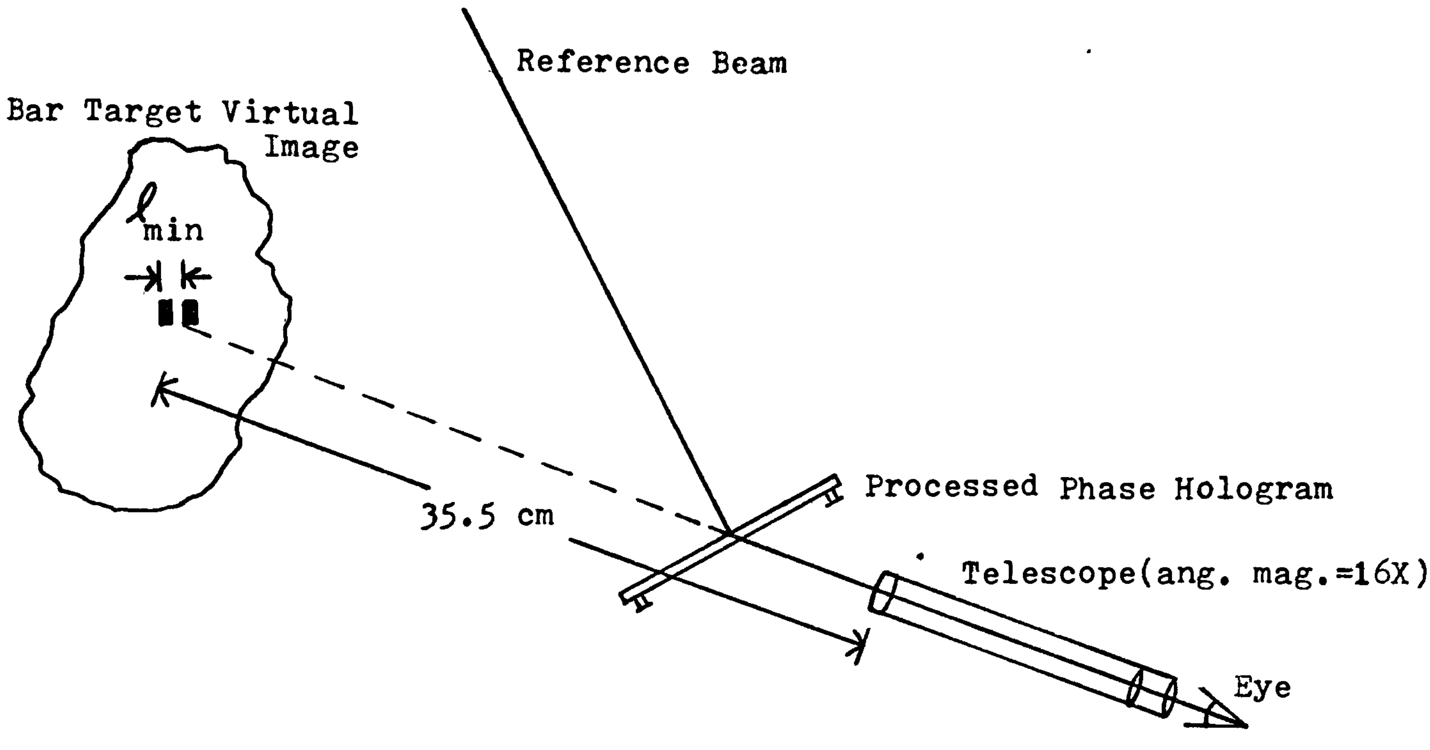


FIGURE 4 APPARATUS FOR RESOLUTION DETERMINATIONS

Resolution data for each hologram was obtained subjectively from an observer viewing the reconstructed image of the alphanumeric target through a telescope(object distance=35.5 cm, angular magnification= 16X). See Figure 4 .

RESULTS

The data for noise, resolution and reconstruction ratio as a function of density and bleach concentration were analyzed by regression analysis. Specifically, a Forward Doolittle regression method[12] was used and from this, the the significant factors, mathematical relationships and interactions of the factors were determined.

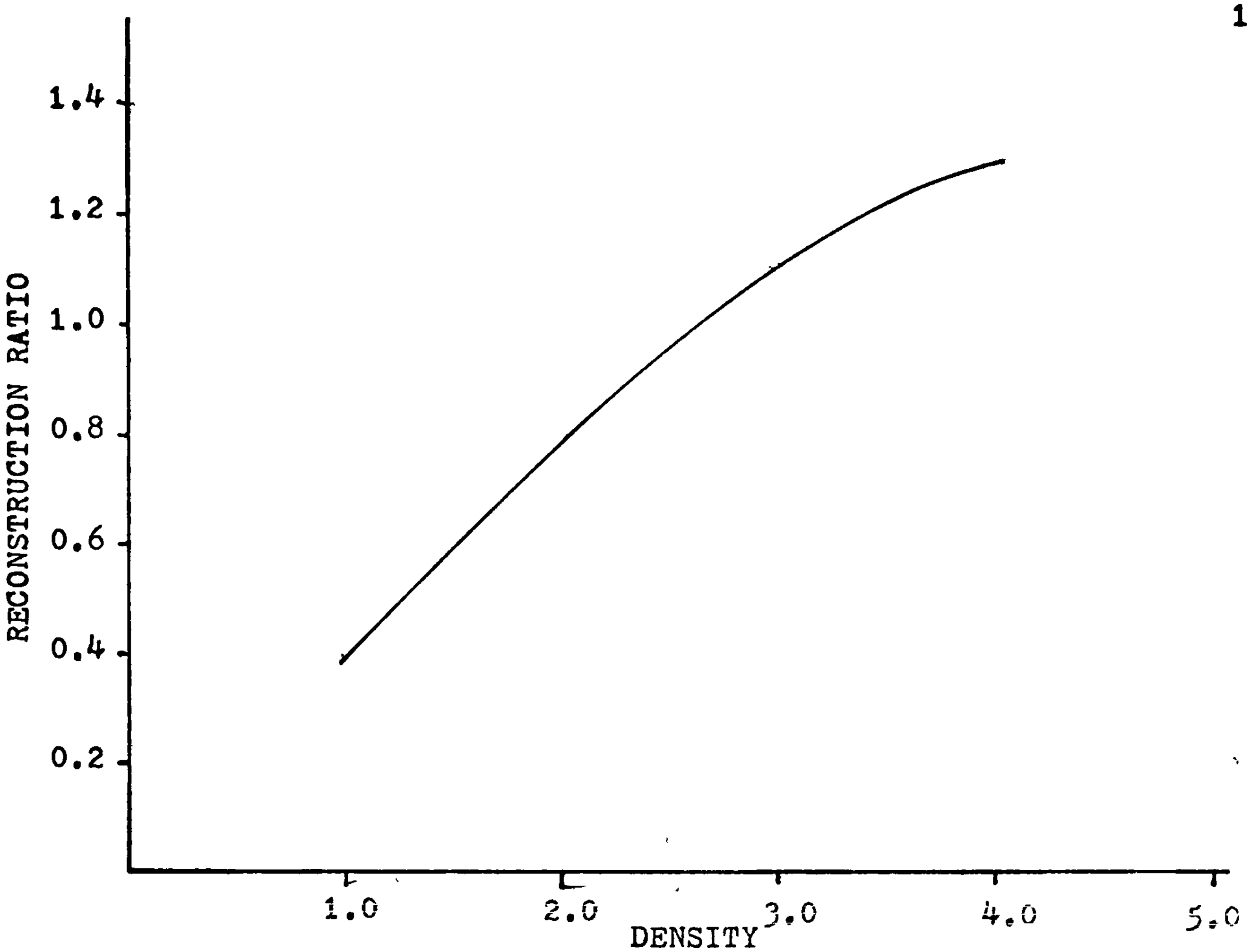


FIGURE 5 Graph showing the relationship between reconstruction ratio R and pre-bleach density of the holographic emulsion.

Statistical analysis of the data verifies that changes in bleach concentration do not significantly affect noise, resolution or reconstruction ratio. However, the analysis did show that as pre-bleach density is increased, the reconstruction ratio increases according to a quadratic equation. See Figure 5 .

The second response variable under consideration was the relative noise of the holographic images. Noise, also,

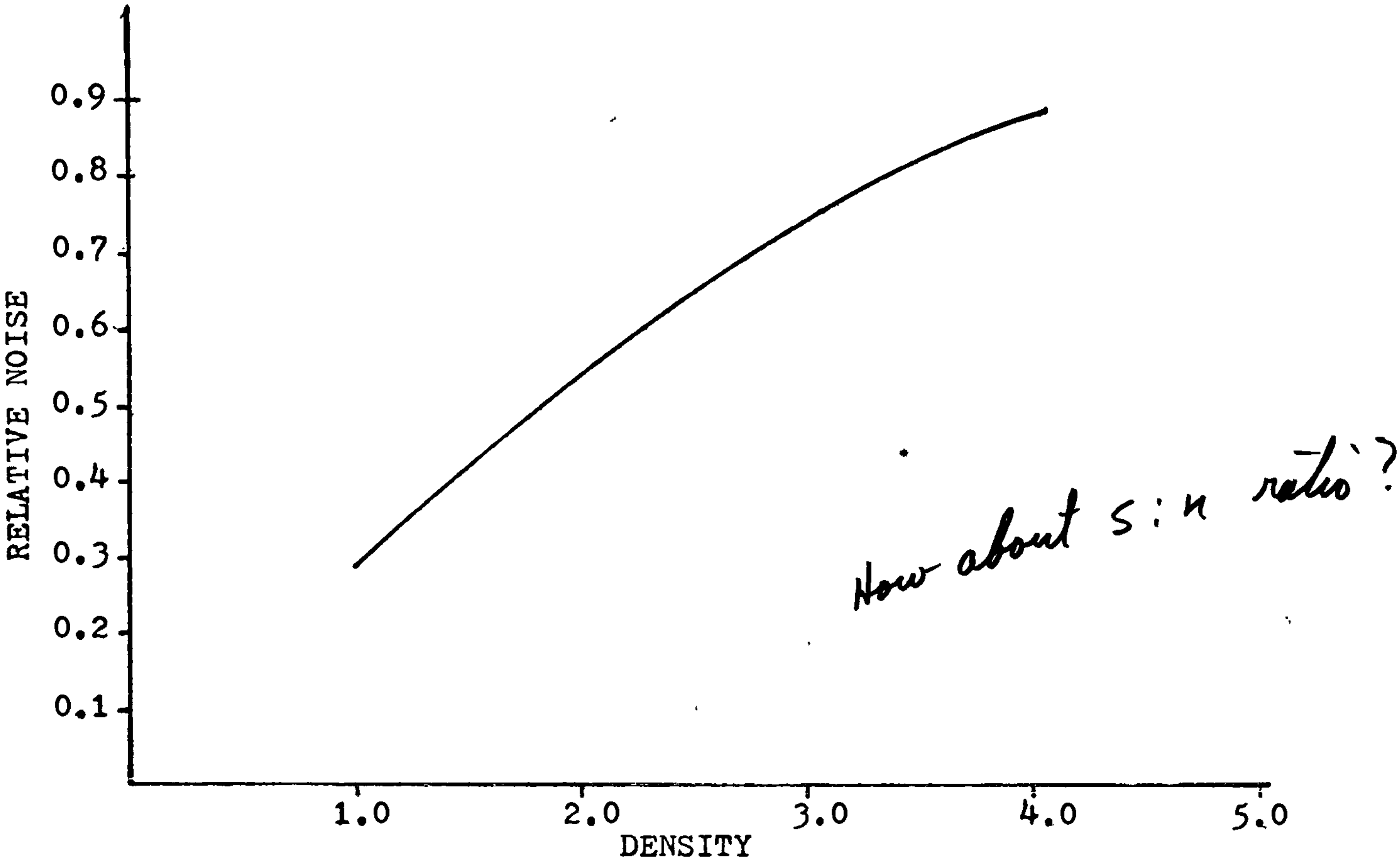


FIGURE 6 Graph showing the relationship between holographic image noise and pre-bleach density of the holographic emulsion.

was found to increase in a quadratic relationship with pre-bleach density.

The third response variable in this experiment was resolution which was found to be unaffected by an increase in the pre-bleach density of the hologram. The average angular resolution of this system was 8.87×10^{-4} radians (measured from the hologram to the image plane). The reason that resolution is unaffected by an increase in density can be seen by analyzing both Figures 5 & 6. In Figure 5, it is seen that if density is increased from 2.00 to 4.00 , the R value increases by a factor of 1.65 . Likewise, in Figure 6, if density is also increased from 2.00 to 4.00 , the noise level increases by a factor of 1.67 . Since noise and reconstruction ratio increase by approximately the same magnitude, the signal-to-noise ratio essentially stays constant. In summary, increasing the density of the holographic film will cause the reconstruction ratio to increase but will not change the resolution of the system .

OBSERVATIONS

During the course of experimentation, repeatability of results was found to be affected by development temperature, bleach temperature and the agitation method used in each of these solutions. The agitation used in the bleach has to be sufficiently vigorous or patches of silver will be present at the completion of the processing step.

For all processing runs made, a pre-exposed control strip on a 35 mm black and white film was processed along with each set of holograms in order to monitor the development stage of the sequence. All processing runs used in the data analysis were found to be acceptable in terms of variability.

Aside from processing chemistry, it is important to note the drying method used for processed phase holograms. When drying holograms, care should be taken to avoid water spots left on the emulsion surface. If water spots are left on the emulsion surface, non-uniformities may result which show up as semi-opaque when the hologram is reconstructed. Since the viewing position of the observer was fixed when resolution measurements were made, an opaque area of the hologram might cause erroneous data. Any hologram showing this defect was not counted and these exposures were repeated.

CONCLUSIONS

The intent of this thesis was to quantitatively define the effects upon three important factors in a holographic image which may vary due to bleach concentration and density level. As our experimentation and data indicate, the exposure incident upon the film(and its corresponding density) has the single greatest effect on the brightness of the holographic image. This increase that results from high densities, however, also increases the noise in the image. These two effects combine and, consequently, do not yield holograms of increased resolution.

It was also determined in this investigation that the concentration of the bleach solution has no effect upon noise, resolution or reconstruction ratio.

In general then, it can be concluded for the system used in this investigation that high densities can be used to record efficient phase holograms without any loss of resolving power in the image plane.

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APPENDIX

A 3^2 Factorial

FACTOR B BLEACH CONCENTRATION	FACTOR A- DENSITY		
	Low	Medium	High
Low			
Medium			
High			