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Characteristics of Holograms Recorded on AGFA 10E75 Plates and Processed in D6X Developer

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CHARACTERISTICS OF HOLOGRAMS RECORDED ON AGFA
10E75 PLATES AND PROCESSED IN D6X DEVELOPER

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ABSTRACT

This study evaluates the results obtained using a new developer (D6X) to produce certain types of holograms on Agfa-Gevaert 10E75 plates. D6X developer when used to produce a gamma of one on 10E75 plates, can produce amplitude holograms with 65 percent of the diffraction efficiency (η) of D-19 with a superior signal-to-noise ratio (S/N). The D6X amplitude holograms are comparable in η and S/N to D-19 plates recorded with higher reference-to-object beam ratios; 1.3 percent efficiency with an S/N of 80 was obtained. The D6X processed plates need only one-half the exposure energy required of D-19 for amplitude holograms, but the exposure latitude is 30 percent larger. For holograms bleached in cupric bromide, the D6X produced lower η but had a greatly superior S/N compared to normal bleached D-19 plates. The effect of D6X was comparable to hardening the emulsion in Kodak SH-5 before development in D-19. Bleached efficiencies of 7.4 percent with an S/N of 70 were obtained. D6X can produce bleached holograms with $\eta \geq 3\%$ and an S/N ≥ 70 over an exposure range of two orders of magnitude.

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CHARACTERISTICS OF HOLOGRAMS RECORDED ON AGFA 10E75 PLATES AND PROCESSED IN D6X DEVELOPER

Introduction

In order to produce Fourier transform filters with a gamma near 1.0, a low contrast developer designated as D6X was formulated.¹ Preliminary data indicated that holograms made on Agfa-Gevaert Scientia 10E75 glass holographic plates and processed in D6X to a gamma near 1.0 had diffraction efficiencies approximately 60 percent of the efficiency that would have been obtained had the same plates been processed in Kodak D-19 developer.

The fact that a low contrast (gamma ~1.0) process could produce holograms with nearly two-thirds of the diffraction efficiency of a high contrast (gamma ~6.0) process was unexpected. The work reported here is a more thorough investigation of 10E75 plates used with D6X to make amplitude as well as phase type holograms. The phase type holograms were obtained by bleaching the amplitude holograms in a solution of cupric bromide.

Experimental Results

The recording setup and measurement techniques used were identical to those used in other studies of 10E75 plates processed in D-19.^{2,3} Briefly, a hologram of a diffusely illuminated 1951 Air Force resolution chart placed 160-mm from the hologram plate was recorded using a 100-mm diameter collimated reference beam, 16 degrees off axis. A single frequency TEM₀₀ He-Ne gas laser was used for the light source. Diffraction efficiency, η , and signal-to-noise ratio, S/N, were measured for the virtual image reconstructed at the center of the hologram by a 10-mm diameter reference beam. S/N was measured in the 10X magnified virtual image, while η was measured as the fraction of incident energy diffracted to the virtual image directly behind the plate.

Attention should be called first to the D-Log E data illustrated in Figure 1. The processing sequence used is shown below.

Development (20° C)	5 minutes
Kodak Stop Bath	30 seconds
Kodak Rapid Fixer	4 minutes
Water Wash	10 minutes
Kodak Photo-Flo	30 seconds
Dry at room temperature	

Not only does the 5-minute D6X process produce a much lower contrast, but it increases the toe speed compared to that of D-19. A density of 0.7 with D6X for 5 minutes requires an exposure of only 21 ergs/cm^2 , while for similar D-19 processing 32 ergs/cm^2 is needed. Less total energy is required, and the lower gamma makes precisely accurate exposure energies less important.

Figure 1. Sensitometric curves of unbleached Agfa-Gevaert 10E75 plates of lot No. 574918. Exposure was with a Macbeth Quantalog Sensitometer using a $10\text{\AA}$ bandpass $6328\text{\AA}$ filter. Density measurements were with a spectral-diffuse Macbeth Quantalog Densitometer. Both D-19 and D6X developer data are given.

If a 3-minute Kodak SH-5 Hardener bath is used to treat the plates before development, it is seen that the sensitivity is reduced by at least a factor of two.

After the plates were developed they were dried before η and S/N were measured. After measurement, the plates were bleached with cupric bromide in the manner described by Lehmann,⁴ et. al., with the exception that no prehardener was used. Earlier work³ had determined this technique to be desirable for 10E75 plates processed in D-19. No data were available to indicate that this bleach would be optimum for D6X; but direct comparisons of η and S/N to the bleached D-19 data would be possible.

Figure 2 shows the diffraction efficiency data for both D-19 and D6X before and after bleaching. Three different reference-to-object beam ratios, K , were used. For $K=1$, the unbleached D-19 curve peaks at 2.0 percent near an optical density of 0.75 (OD 0.75). The corresponding D6X ($K=1$) curve peaks at 1.3 percent, nearer to OD 0.50. This confirms that D6X can produce amplitude hologram efficiencies nearly two-thirds (actually 65 percent) of that obtained with D-19. At this lower density level (0.5 vs 0.75), D6X requires only one-half the exposure energy used for an optimum D-19 developed amplitude hologram (see Figure 1). D-19 ($K=4$) data were included because the D-19 maximum amplitude diffraction efficiency is nearly equal to that of D6X ($K=1$). D-19 ($K=1$) produced the highest η in the unbleached state, but after bleaching its value of 15 percent falls slightly below the 16 percent of bleached D-19 ($K=4$). The bleached η of D6X ($K=1$) falls considerably below that of D-19 ($K=4$) for all densities above OD 0.9, but efficiencies of nearly 10 percent can be achieved above OD 1.5. A second D6X with $K=9$ was included because it was anticipated that D6X ($K=1$) would not give satisfactory bleached S/N values. This D6X ($K=9$) does not extend to low enough densities to determine a peak unbleached η because only its bleached results were of interest.

Figure 2.

Diffraction efficiency of the virtual image for various reference-to-object beam ratios and two different developers both before and after bleaching in cupric bromide.

The complete bleach procedure contained in Reference 4 includes a prehardening step in Kodak Hardener SH-5 before development. This increases the S/N at the expense of η for both the bleached and unbleached cases. The disadvantage is that the speed of the emulsion is decreased in proportion to the length of time it remains in the prehardening bath. Three minutes were found to be an optimum prehardening time for bleached holograms. Figure 3 is the η vs OD data for three series of $K=9$ plates. One series was processed in D6X, one in straight D-19, and the third was soaked for 3 minutes in SH-5 before D-19 development. The η curves of D6X and the prehardened D-19 are roughly similar, falling below a D-19 ($K=9$) whether or not the plates are bleached. The difference is that D6X is more sensitive than normal D-19 below OD 0.8, while prehardened D-19 is always a factor of two slower (see Figure 1).

Figure 3.

Diffraction efficiency of the virtual image for a reference-to-object beam ratio of 9 using D6X and Kodak D-19 developers.

First let us consider the S/N of only unbleached holograms. Figure 4 is the before-bleach S/N corresponding to the η curves of Figures 2 and 3. The S/N at the η peak of D6X ($K=1$) is 80 at OD 0.5, while the nearly equivalent η peak of D-19 ($K=4$) at OD 0.75 produces a S/N = 90. It should be noted that at the peak η of a D-19 ($K=1$) curve at OD 0.75, the S/N value is only slightly over 20. When the beam ratio is increased to $K=9$, the three different development techniques produce an S/N at peak η which vary somewhat, but all are approaching 200.

Figure 4.

Signal-to-noise ratio of the virtual image for various reference-to-object beam ratios and two different developers before bleaching.

Figure 5 is identical to Figure 4 except the data were taken after the plates were bleached in cupric bromide. The D-19 curves reach an η peak somewhere in the range of OD 1.5 to 2.0, while the S/N monotonically decreases with increasing density. To make use of the higher S/N, the discussion of bleached D-19 below will assume a before-bleach density of OD 1.5. The D6X does not produce such smooth curves. The discussion below will always mention the D6X before-bleach density being considered for each case.

Figure 5.

Signal-to-noise ratio of the virtual image for various reference-to-object beam ratios and two different developers after bleaching in cupric bromide.

The S/N of 10 with η of 16 percent for the bleached (K=4) D-19 is low but not nearly as low as the S/N = 2 with η of 15 percent for bleached D-19 (K=1). By comparison, the bleached D6X (K=1) produces an S/N of 25 near its first efficiency peak at OD 0.9, corresponding to an η of 8 percent. Although the S/N of the D6X holograms is higher, the η is lower. There seems to be no combination of factors to produce an amplitude D6X (K=1) hologram with both η and S/N preferable to that of D-19 (K=4).

At K=9, the bleached D-19 produces 12 percent efficiency with an S/N of 26. Simply pre-hardening the emulsion before D-19 development results in only 6 percent efficiency but with an S/N of 70. The D6X curve has two peaks, one near OD 1.0 and the other near OD 2.3. At OD 1.0, D6X (K=9) gives an η of 5 percent with S/N = 105, while at OD 2.3 the η increases to 7.4 percent with S/N of 70. Before bleaching, these three methods gave comparable S/Ns. After bleaching, the D6X and prehardened D-19 have greatly superior S/N ratios when compared to the nonhardened D-19. The interesting point is that the bleached S/N of the D6X is not a sharply decreasing function of density. Bleached holograms with exceptionally good S/Ns (in excess of 70) can be made from D6X plates with densities of any value between OD 0.7 and OD 2.7.

In addition to the S/N and sensitivity advantages, the D6X process is a low contrast process which gives a larger exposure latitude. A nonhardened D-19 ($K=4$) amplitude hologram with $\eta \geq 1\%$ has a density in the range of OD 0.4 to 1.25. These densities correspond to an exposure energy range of 1.6X. A similar amplitude D6X hologram would fall in the range of OD 0.35 to 0.85. Even though the permissible density range is smaller than D-19, the exposure energy range of 2.1 is 30 percent larger. Similar arguments can be made for bleached D6X holograms. Bleached D6X holograms with $\eta \geq 3\%$ and $S/N \geq 70$ can be produced with densities anywhere in the range of OD 0.7 to 2.7, corresponding to an exposure latitude of nearly two orders of magnitude.

Conclusions

D6X can be used to process 10E75 hologram plates. The maximum amplitude hologram efficiency is near 1.3 percent for a complex object, while a similarly recorded hologram processed in D-19 will deliver 2.0 percent. Although efficiency is down, the signal-to-noise ratio is markedly better. The η and S/N of a D6X ($K=1$) unbleached plate is nearly identical to that of a D-19 ($K=4$) plate.

If the plates are to be bleached to make phase type holograms, the result of using D6X was found to be roughly equivalent to prehardening the emulsion with Kodak SH-5 before development in D-19. The resultant plates exhibited reduced efficiency but greatly enhanced S/N compared to a normal D-19 bleached hologram. The important difference is that a D6X processed plate is more sensitive than one done in D-19 for densities below 0.8, while a prehardened D-19 is a factor of 2 less sensitive than a standard D-19.

The large exposure latitude afforded by the low contrast of D6X makes precise control of laser exposure energy less critical. Good amplitude holograms can be produced over an energy range of 2.1X. If bleaching is necessary, even larger exposure latitudes are possible. Depending upon the parameters of importance, an exposure latitude of two orders of magnitude is possible with bleached D6X holograms.

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APPENDIX

The chemical composition of D6X is given below. Dissolve each chemical in the order given in 500 ml of water.

2 gr	1-phenyl-3-pyrazolidone
3 gr	P-methylaminophenol sulfate
1.5 gr	$\text{Na}_2 \text{CO}_3$
30 gr	$\text{Na}_2 \text{SO}_3$

Add additional water to make 1.0 liter

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