DIS NDT Diagnostic Imaging Systems Division

Technical Information

NDT/Holography

1. Introduction

Photographic materials for holography

Photographic materials for holography must meet specific requirements. Since the dimensions of the structure of the interference pattern to be recorded are usually of the order of magnitude of the wavelength of the light used for exposure, a very high resolving power is essential. A high speed is also desirable to allow short exposures.

However, high resolving power and high speed are somewhat incompatible properties, which makes it necessary to arrive at a compromise of the highest possible efficiency. The nature of the subject will determine whether the ideal solution of this problem will be slanted towards high speed or high resolving power.

According to the above principles, Agfa-Gevaert has developed 4 types of HOLOTEST photographic materials:

- 10 E 75 — High sensitivity - size of grain approx. 90 nm, resolving power approx. 3000 lines/mm, to be used with red light emitting lasers.
- 10 E 56 — Same properties as the 10 E 75 material, but to be used with green light emitting lasers.
- 8 E 75 HD — Size of grain approx. 35 nm, very high resolving power of approx. 5000 lines/mm, lower sensitivity than 10 E 75, to be used with red light emitting lasers.
- 8 E 56 HD — Same properties as the 8 E 75 HD material, but to be used with green light emitting lasers.

2. Amplitude holography

2.1. Density and amplitude transmission curves

The relation between density D and exposure E is usually represented by the characteristic curve. Fig. 1 shows these curves for HOLOTEST emulsions 8 E 75 HD and 10 E 75 for red laser light, 8 E 56 HD and 10 E 56 for blue and green laser light respectively.

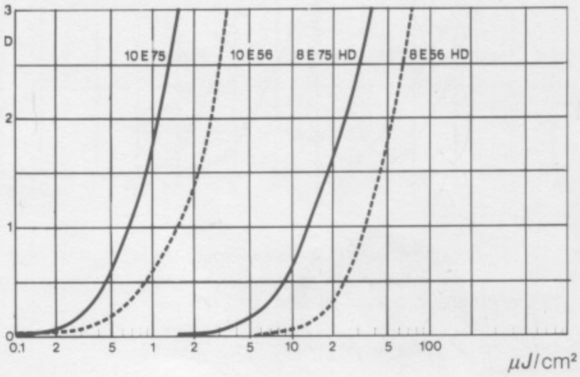

Fig. 1

Exposures of HOLOTEST 8 E 75 HD and 10 E 75 were effected with 627 nm, and of 8 E 56 HD and 10 E 56 with 514 nm.
Processing was carried out in G 282 (1 + 2) for 4 minutes at 20°C. After an intermediate rinse in water (1 minute at 20°C), fixing was carried out in Agfa-Gevaert fixing bath G 321 for 4 minutes, followed by washing for 15 minutes. The density of the developed emulsion layers was measured by parallel light. Characteristic curves contain useful information in the case of certain holographic exposures, but in general amplitude transmission curves are preferred, because a hologram acts as a diffraction screen to the incident wave front, where not the local density but the local amplitude transmission is the more important consideration.
Amplitude transmission is defined as the ratio between the amplitudes of a monochromatic plane wave after and before passing through the photographic emulsion. This is usually a complex quantity; in other words, not only the amplitude but also the phase of the incident radiation is affected. However, in the case of processed emulsions, for measuring amplitude transmission $|T_a|$ the only easily measured quantity is intensity transmission $T_i = T_a T_a^*$, where T_a^* represents the complex conjugate of T_a.
This quantity is expressed as a function of the exposure of HOLOTEST 8 E 75 HD and 10 E 75 at a wavelength of 627 nm, and of HOLOTEST 8 E 56 HD and 10 E 56 at a wavelength of 514 nm respectively, in Fig. 2.
The energy per unit surface that corresponds to $|T_a| = 0.5$ can be regarded as an indication of the sensitivity.

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Approximate values of light intensities for $|T_a| = 0.5$ (corresponding to D = 0.6) are

~ 0.5 $\mu J/cm^2$ for 10 E 75
~ 10 $\mu J/cm^2$ for 8 E 75 HD
~ 1 $\mu J/cm^2$ for 10 E 56
~ 25 $\mu J/cm^2$ for 8 E 56 HD

These values will also be slightly affected by the processing conditions.

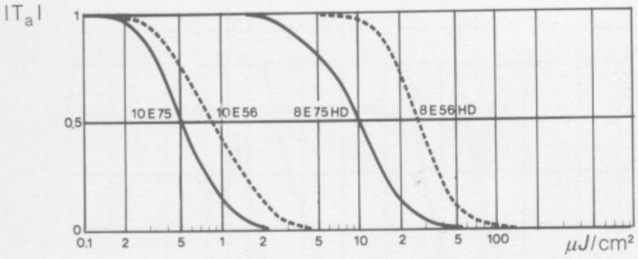


Fig. 2

Amplitude transmission curves at λ = 514 nm ----
λ = 627 nm —
Dev. G 282 c (1 + 2) - 4 min - 20°C

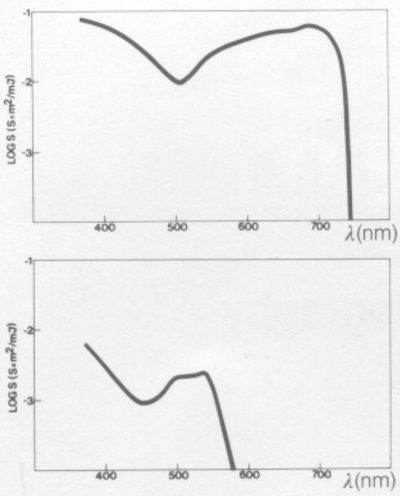
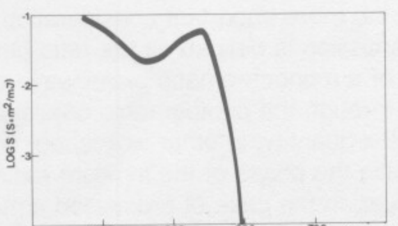


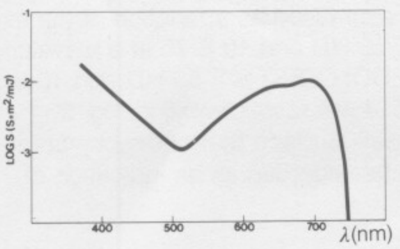
Fig. 3

Absolute spectral sensitivity.
Curves to obtain a D = 0.60 above fog.

2.2. Colour sensitivity

HOLOTEST holographic emulsions 8 E 75 HD and 10 E 75 are specially sensitized for wavelengths between 600 and 750 nm, and are intended for use with the He-Ne laser (633 nm) and the ruby laser (694 nm). On the other hand, HOLOTEST holographic emulsions 8 E 56 HD and 10 E 56 are suitable for exposure to wavelengths up to 560 nm (krypton and argon lasers). The density and amplitude transmission curves given in Section 2.1 apply to the wavelength of the He-Ne laser of 633 nm and those of the krypton laser of 476 and 521 nm. To enable one to convert the exposure to other wavelengths, the absolute spectral sensitivities are shown in Fig. 3.





2.3. Image quality

An optical diffraction method was used to determine the image quality of the holographic emulsion. A double-beam interference exposure enabled us to examine the resultant diffraction screen. Fig. 4 shows in schematic form both the exposure and the reconstruction.

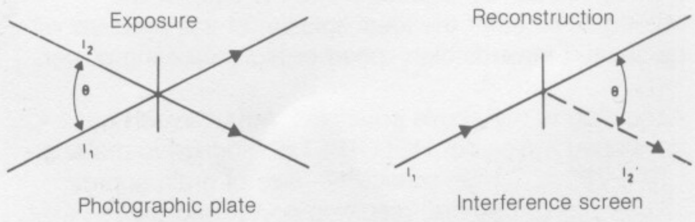


Fig. 4

Schematic representation of exposure and reconstruction of double-beam interference.

During exposure, two plane waves having intensities I_1 and I_2 were incident on the photographic plate, each at the same angle to the normal. Representing the angle between the two rays by θ, spatial frequency f is given by

$$f = \frac{2}{\lambda} \sin\frac{\theta}{2}$$

where λ = wavelength in air (633 nm for the He-Ne laser). With $\theta = 90°$, a spatial frequency of 2,235 lines/mm will then result. The separation between adjacent lines will then be the inverse of the spatial frequency equal to approx. 0.45 micron.

Modulation m depends on the polarization of the laser radiation and intensity ratio I_1/I_2. In the case described, lasers with linearly polarized radiation were used. The electric vector was normal to the plane of incidence. The intensity ratio I_1/I_2 amounted to 0.5, corresponding to a modulation of 0.94. In general the modulation caused by the polarization considered here is

$$m = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$$

Reconstruction took place as shown in Fig. 4. Ray I_1 was used for reconstructing ray I_2'. Intensity I_2' was a diffraction of the first order and hence ratio I_2'/I_1 is dependant on angle θ, modulation m, and the exposure. Fig. 5 shows ratio I_2'/I_1 against exposure.

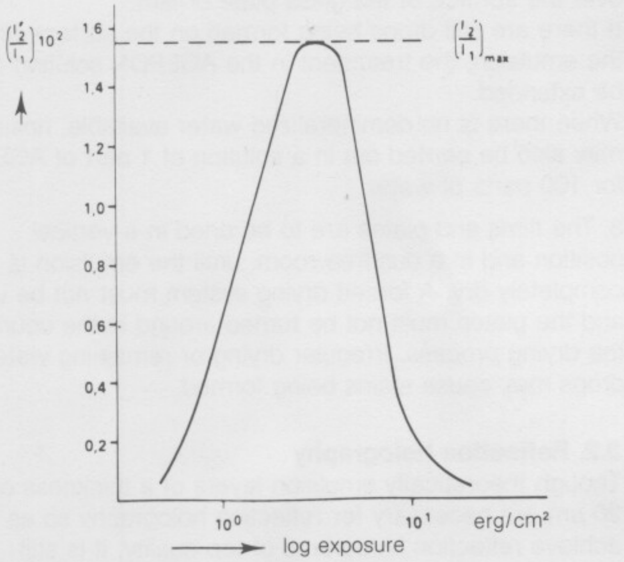


Fig. 5

Dependence of diffraction efficiency on exposure

This function has a definite maximum. Ratio I_2'/I_1 can be considered as a measure of the quality of a screen and is therefore called diffraction efficiency. Fig. 6 and 7 show the optimum diffraction efficiency $(I_2'/I_1)_{max}$ as a function of the spatial frequency for HOLOTEST emulsions 10 E 75 and 10 E 56 respectively. Intensities I_1 and I_2' have not been corrected for Fresnel reflection, because the latter corresponds to the practical applications of holography. The actual diffraction efficiency of the photographic emulsion for the polarization used is higher still, especially at large values of angle θ. We should mention that the material was over-modulated by using the large modulation values of 0.94 or 1. In other words, this is not a case of linear transfer; intensities of higher orders of diffraction are also obtained. In order to compare the diffraction intensity to noise I_N at various spatial frequencies, exposures were carried out with a single laser beam of the same overall intensity, and the photographic plates were all processed and measured under identical conditions. The resultant ratio I_N/I_1 is also shown in Figs 6 and 7.

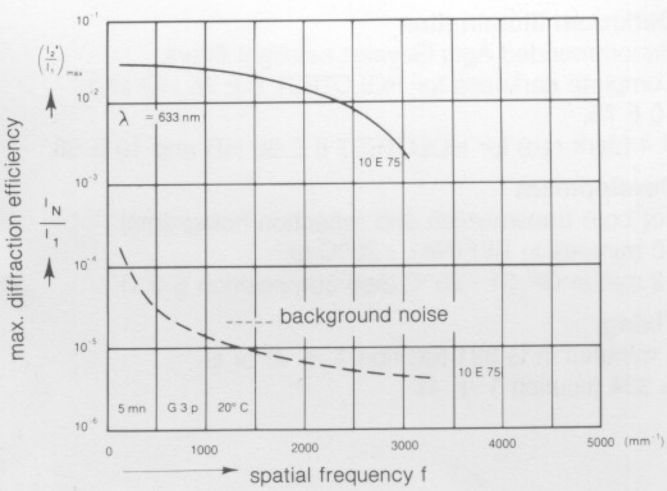


Fig. 6

Maximum diffraction efficiency against spatial frequency, E-vector normal to plane of incidence; modulation 0.94.

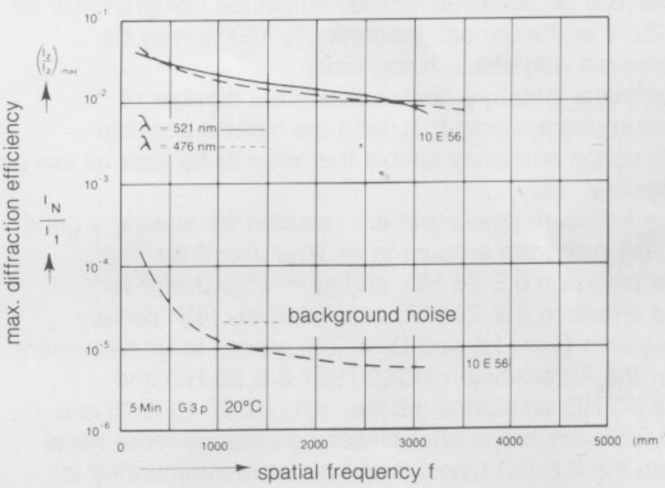


Fig. 7

Maximum diffraction efficiency against spatial frequency, E-vector normal to plane of incidence; modulation m = 1.

2.4. Reciprocity behaviour

Q-switch lasers with pulsewidths of 10 to 50 ns are used for short exposures. In this case, the reciprocity behaviour of HOLOTEST emulsions is obviously important. To obtain densities $D \leq 2$, the exposure of HOLOTEST materials must be multiplied 2 to 4 times when Q-switch lasers are used.

2.5. Processing

Darkroom illumination

Recommended Agfa-Gevaert safelight filters:
Complete darkness for HOLOTEST 8 E 75 HD and 10 E 75,
R 4 (dark red) for HOLOTEST 8 E 56 HD and 10 E 56.

Development

(for both transmission and reflection holograms)
10 minutes in REFINAL - 20°C or
2 min in GP 61 - 20°C (see composition § 3.1)

Fixing

4 minutes in G 321 (dilution 1 + 4) or in
G 334 (dilution 1 + 4).

3. Phase holography

3.1. Transmission holography

Where theoretically the maximum diffraction efficiency that may be achieved with an amplitude hologram will be 6.25 % at the utmost, theoretically 100 % may be achieved with phase holograms.
Technical literature describes a great number of processing systems that, with the highest possible diffraction efficiency enable the noise to be kept as low as possible.
The exposure doses that are required for making a good phase hologram amount to ~ 50 μ *J*/cm² for the emulsion 8 E 56 HD, and to ~ 25 μ *J*/cm² for the emulsion 8 E 75 HD, as a relatively high density (between D = 1.5 and D = 2.5) proves to be necessary.
For the Agfa-Gevaert HOLOTEST 8 E 56 HD and 8 E 75 HD emulsions (as the HOLOTEST 10 E 75 and 10 E 56 emulsions after bleaching produce more noise than the 8 E HD types, they are not recommended for phase holography) the following processing is proposed:

1. Development:
10 min. in REFINAL (20°C), or
2 min. in GP 61 (20°C) made up as follows:

GP 61

Water	700	ml
METOL	6	g
Hydroquinone	7	g
Phenidone	0.8	g
Na_2SO_3	30	g
Na_2CO_3	60	g
KBr	2	g
Na_4EDTA	1	g

water to make 1 litre

2. Intermediate rinsing in running water: 2 min. (temperature 20°C ± 2°C).

3. Fixing in Agfa-Gevaert G 321 (1 + 4) rapid fixing bath, for 2 min. (temperature = 20°C ± 2°C).

4. Intermediate rinsing in running water: 2 min. (temperature 20°C ± 2°C).

5. Bleaching in a bleaching bath made up as follows:

GP 431

Water	600	ml
$Fe(NO_3)_3.9H_2O$	150	g
KBr	30	g

300 mg of phenosafranin dissolved in 200 ml of ethanol.
water to make 1 litre.
To be used in a dilution of: 1 part GP 431 + 4 parts of water (temperature = 20°C ± 2°C).
The keeping quality of the ready-to-use bleaching bath in closed bottles is limited (approx. 1 week).

6. Rinsing in running water: 5 min.

7. Rinsing in demineralized water with 1 part of AGEPON for 200 parts of water, for 2 min. at 20°C.
After the treatment, the water should be evenly distributed over the surface of the glass plate or film.
If there are still drops being formed on the surface of the emulsion, the treatment in the AGEPON solution is to be extended.
When there is no demineralized water available, rinsing may also be carried out in a solution of 1 part of AGEPON for 100 parts of water.

8. The films and plates are to be dried in a vertical position and in a dustfree room, until the emulsion is completely dry. A forced drying system must not be used and the plates must not be turned around in the course of the drying process. Irregular drying or remaining water drops may cause stains being formed.

3.2. Reflection holography

Though theoretically emulsion layers of a thickness of 20 μm are necessary for reflection holography so as to achieve reflection holograms of top quality, it is still recommended to use the materials 8 E 56 HD and 8 E 75 HD with a thickness of the emulsion layer of 7 μm, as with these materials the distortion of the Bragg planes after processing will be smaller. This is why it is also possible to achieve high-quality reflection holograms on thinner emulsion layers.

The following processing is proposed:

I. Processing when the colour of the hologram has to approximate as closely as possible to that of the laser light.

1. Development: 2 min. at 20°C in a developer of the following composition:

GP 62

Part A		**Part B**	
water	700 ml	water	700 ml
METOL	15 g	Na_2CO_3	60 g
pyrogallol	7 g	demineralized water up to	1000 ml
Na_2SO_3	20 g		
KBr	4 g		
Na_4EDTA	2 g		
water up to	1000 ml		

Use:
1 part A + 2 parts of water + 1 part B
Parts A and B keep well as separate solutions.
The ready to use solution can be used for a limited time only (1 to 2 hours).

Therefore parts A and B should be mixed immediately before use.
Remark: Pyrogallol is a hardening developing substance that may affect the skin. Therefore always wear rubber gloves when working with this developer. So as to achieve good reflection holograms, a density between D = 1.5 and D = 2.5 is to be reached.

2. Intermediate washing in running water: 2 min. (temperature = 20°C ± 2°C).

3. Bleaching: till completely clear in a bleaching bath of the following composition:

GP 432

water	700	ml
KBr	50	g
boric acid	1.5	g
water up to	1000	ml

p-benzoquinone* 2 g/lit. to be added just before use.
The life of the ready to use bleaching bath in a well stopped bottle is limited to 1 week.
Temperature of the bleaching bath: 20°C ± 2°C.

4. Washing in running water: 5 min. (temperature = 20°C ± 2°C).

5. Washing in demineralized water with 1 part of AGEPON to 200 parts of water for 2 min. at 20°C.
After treatment the water must be evenly spread on the surface of the glassplate or film.
If there is still a formation of drops on the emulsion surface the treatment in the AGEPON solution must be prolonged.
When no demineralized water is available, washing can possibly be done in a solution of 1 part of AGEPON to 100 parts of water.

6. Drying should take place upright, in a dust-free room until the emulsion is completely dry. Do not use forced drying and never turn the plate during drying.
Uneven drying or drops of water which remain on the emulsion will give rise to stains.

II. Colour shifting to a longer wavelength:

To obtain an image in which the colour has been shifted to a longer wavelength than that of the laser light, procedure 1 may be applied. The bleaching bath, however, should be replaced by the following one:

GP 433

water	700 ml
KI	30 g
boric acid	3 g
water up to	1000 ml

Add 2 g/lit. of p-benzoquinone* just before use.
The holographic picture obtained in this way is slightly less sharp than the one of procedure 1. The colour, however, has been shifted to longer wavelengths.

* Caution: The odour of p-benzoquinone in powder form is very irritating and inhaling it may be injurious to health. The following safety measures are to be observed: Always wear rubber gloves when working with this bleaching bath. Wear a mask and ensure that the room is well ventilated.

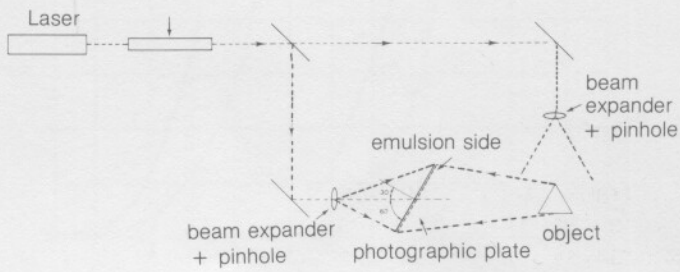
III. Colour shifting to a shorter wavelength:

1. To obtain a holographic picture with a shorter wavelength than that of the laser light the developing bath G 3 p (developing time 2 min. at 20°C), REFINAL (developing time 5 min. at 20°C) or GP 61 (developing time 2 min. at 20°C) is to be used in procedure 1.
The further course of the processing is the same as that of procedure 1.

2. The colour of reflection holograms that are processed the same way as transmission holograms will also shift towards a shorter wavelength.

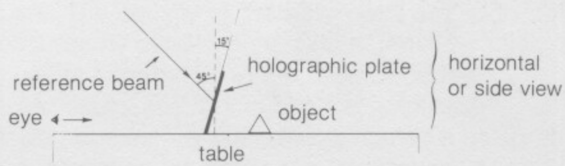
Example of lay-out for reflection holography

beam splitter with adjustment of the intensities of both beams and of the polarization.



Important notes

1. The ratio between the object beam and the reference beam should be 1 - 1.5 to 2.
2. The polarisation of the two beams must be equal.
3. Scattered light that could reach the plate must be avoided.



P.S. The angle of 45° of the reference beam was chosen so that with reconstruction of the hologram, the beam of white light will not reach the eye by reflection.

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