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Memorandum of Project Michigan

THE EFFECT OF FILM-THICKNESS VARIATIONS ON COHERENT LIGHT

ARTHUR L. INGALLS

October 1959

RADAR LABORATORY

Willow Run Laboratories

THE UNIVERSITY OF MICHIGAN

Ann Arbor, Michigan

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The work reported herein was jointly sponsored by the U. S. Army Signal Corps, the U. S. Air Force Air Materiel Command, and the U. S. Air Force Rome Air Development Center.

Robert L. Hess
Technical Director
Project MICHIGAN

ABSTRACT

This report describes the experiments which measured perturbations in monochromatic coherent light caused by variations in film thickness, and discusses the results.

The introduction of commercial photographic film into the aperture of an optical system disturbs the coherence of the transmitted light, because of the variations in thickness and refractive index present in the film. Such variations in film may be made visible, as contour lines, by light interference between the front and back film surfaces. Photographs of the interference pattern were measured, and calculations of light-path variations made. A qualitative analysis showed that film-base thickness-variation was primarily responsible for deterioration of coherence. Formulas are given which show the effect of film variations on coherent light for both use and measurements; and figures are included which show the distribution of film quality.

Few of the commercial films tested were found acceptable by Rayleigh-limit standards; more were satisfactory when immersed in a liquid whose index of refraction nearly equaled that of the film. Index-matching specifications are included which show how nearly the film and liquid indices must match for any particular film quality to affect coherence, due to thickness, by no more than one Rayleigh-limit.

1[1]

INTRODUCTION

Photographic film is being used in a relatively new way recently, placing additional demands on the perfection of film manufacture. The film is used in the aperture of an optical

[1]The material of this report will be presented at the 1959 National Conference of the Society of Photographic Scientists and Engineers, Chicago, Illinois, October 26-30, 1959.

system rather than, as is usual, in the image plane. Geometric patterns are photographed, and this record, called a hologram, is placed in the optical aperture to control the phase of the transmitted light, thereby producing a desired effect in the image plane (Ref. 1 and 2). Unfortunately, variations in film thickness and refractive index affect the phase in random fashion, thus preventing the desired result. Under these conditions of use, variations in thickness, refractive index, and surface quality are of prime importance.

The effect of placing film with nonuniformities in an optical-system aperture is to disrupt orderly wavefronts, causing a diffusion of the light at the image points. This diffusion can take the form of a displacement due to an optical wedge in the film, a defocusing of the image due to the lens power of a spherical depression or projection on the film, or a combination of both. Higher-order effects due to saddle curves and inflection points are also present.

2
EXPERIMENTAL PROCEDURES

A study of these variations in film was made possible by taking photographs of the pattern resulting from interference in monochromatic light occurring at normal incidence between light reflected from the front and back surfaces of the film. The apparatus (Fig. 1) consisted of a 100-watt mercury arc lamp, a piece of flashed opal glass, a curved-object film holder (2-ft cylindrical radius), a 5461 A interference filter and a 4 x 5 view camera. The light source and camera lens were placed close together and approximately at the center of curvature of the film holder. In this way the front and rear surfaces of the film formed a double cylindrical reflector which was tilted to focus the reflected light from the source into the photographic lens, thus filling the lens field with light. It was necessary to close the lens to approximately f/45 in order to get contrasty fringes, as wider openings allowed displacement of fringes with consequent smearing.

As a first test, interference pictures were taken with the above apparatus and sorted into a distribution of visually discrete steps of average fringe concentration. From this distribution, a quality chart (Fig. 2) was constructed with quality ratings ranging from A through H. A chart was also made of the distribution of various different films from six different manufacturers, of which three were domestic and three were foreign (Table I).

At this point two questions needed an answer. They were: (a) whether the base or the emulsion were responsible for the optical variation; and then (b) whether the surface or index were more responsible. To determine these answers, second and third tests were performed.

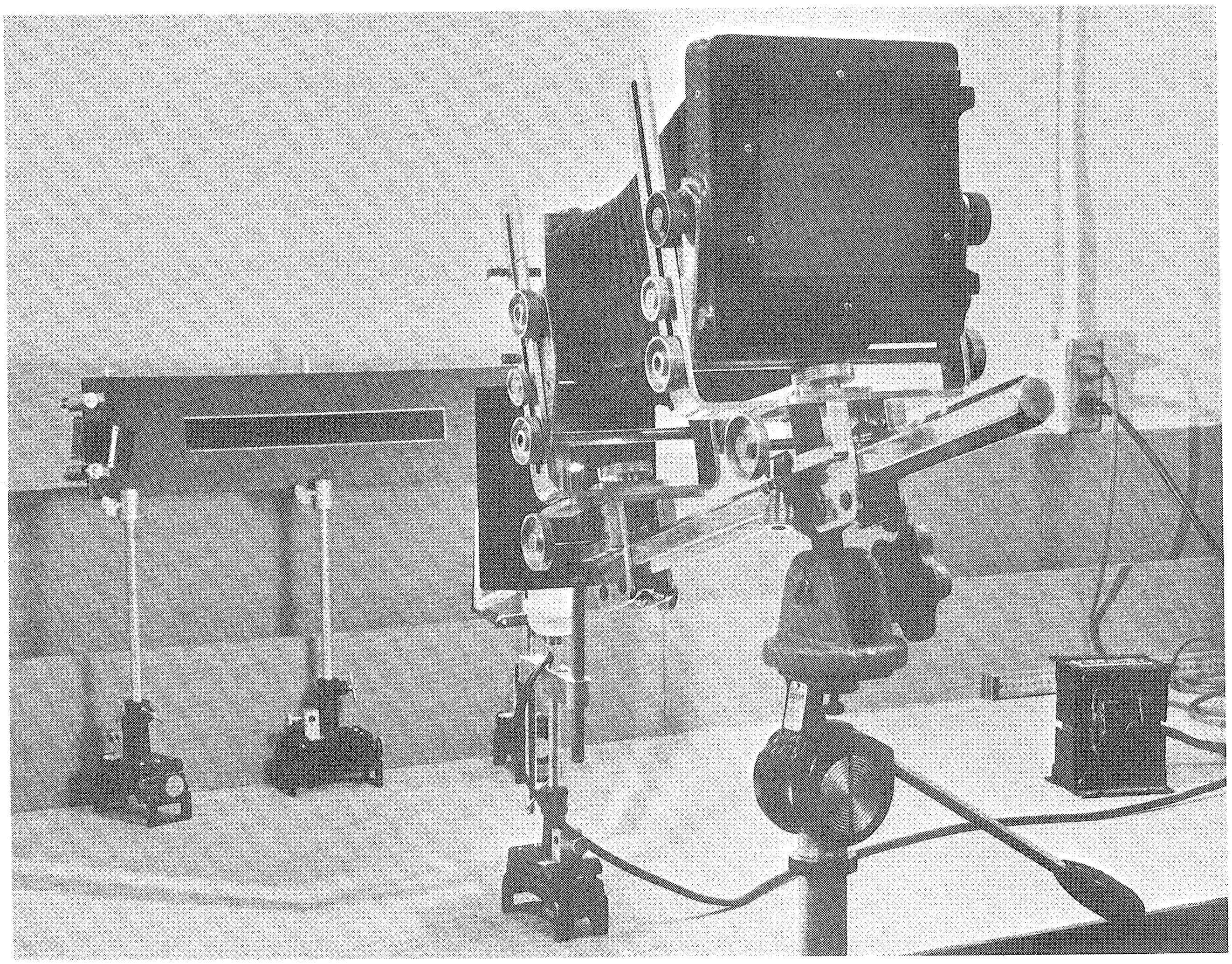

FIG. 1. EXPERIMENTAL APPARATUS. Equipment for photographing interference fringes.

The second test was made by photographing five different films, with and without emulsion, to show whether the film base or the emulsion played the more important part in producing high fringe concentrations. The test was begun by taking a 4-ft strip of film and developing it clear. The film was then cut into two pieces each 2 ft long. The emulsion was then stripped from one piece, and both pieces were photographed, using the techniques and apparatus described above. It was evident that far more difference existed between films than between the same film with and without emulsion (Fig. 3).

The third test was performed to ascertain whether change of thickness or change of refractive index is the more responsible for the variation in optical path length. The test consisted of obtaining light interference between the back and front plano-glass surfaces of a cell and then noting the change in the interference pattern when film alone or film and a liquid of matching

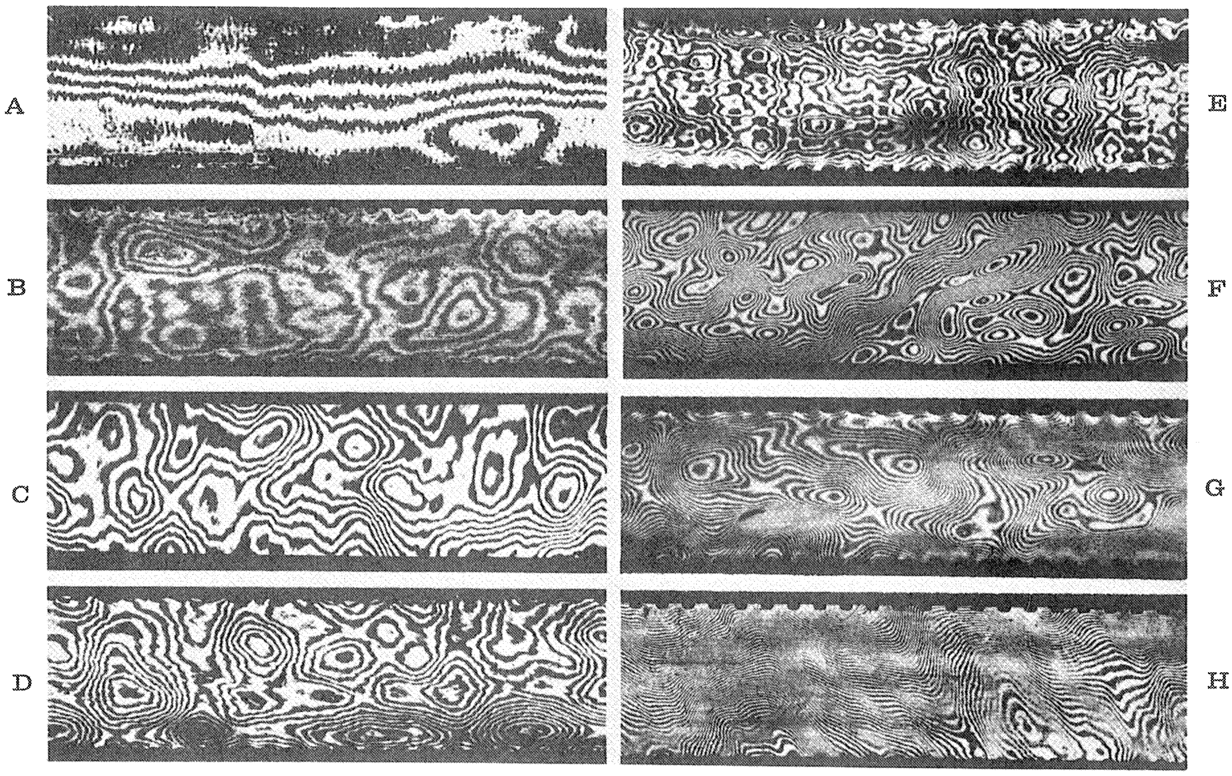

FIG. 2. FILM OPTICAL PATH VARIATION. Interference wavelength = 5461 A.

TABLE I. DISTRIBUTION OF FILM SAMPLES

	Quality							
Mfr	A	B	C	D	E	F	G	H
1	x	xx	x					
2		xxxx	x	x	x	xx		xx
3			xx	x	xx	xxxx		
4				x		xx		
5					x	x	xx	
6						xx		

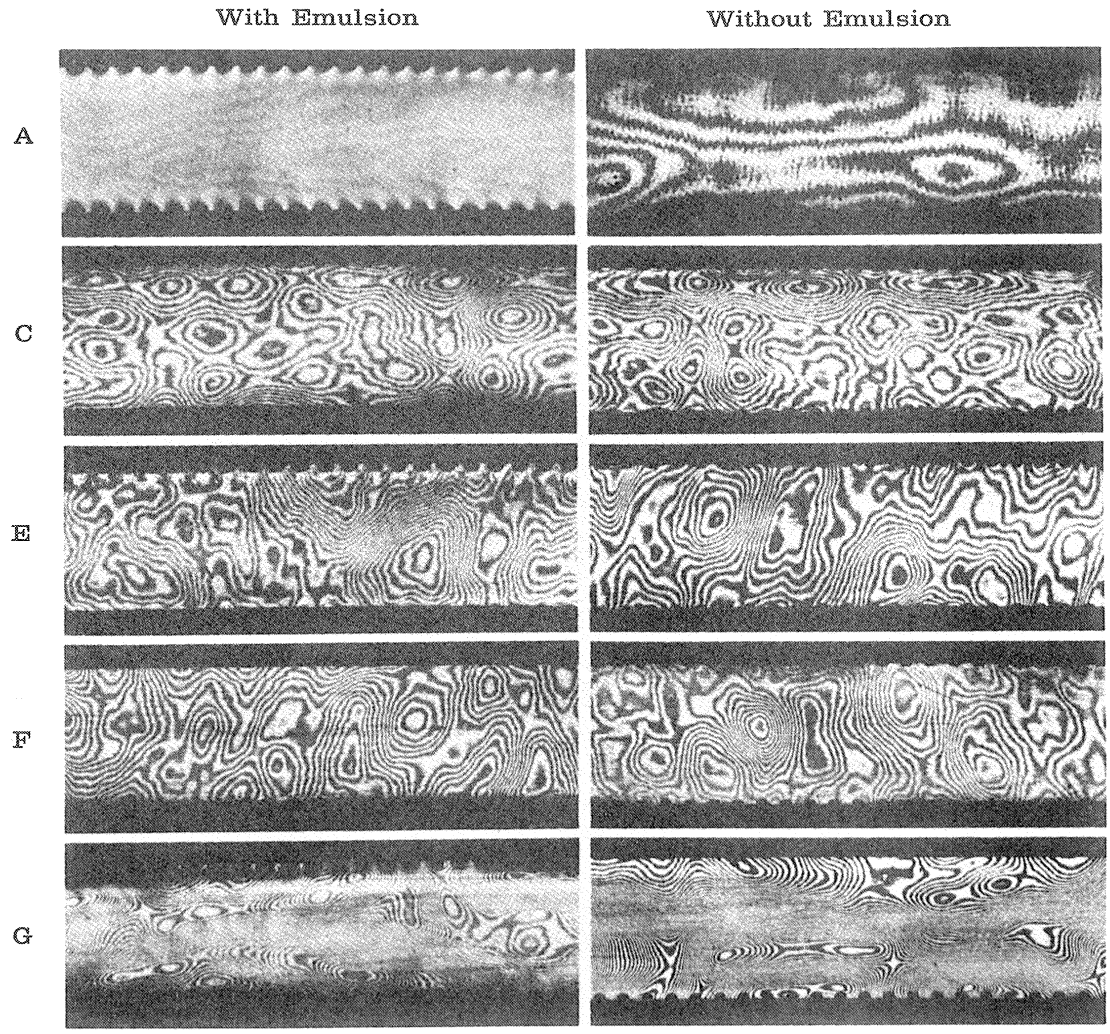

FIG. 3. EFFECT OF EMULSION ON OPTICAL PATH VARIATION. Interference wavelength = 5461 A.

index were introduced into the cell (Fig. 4). The cell plates were half aluminized and adjusted nearly parallel so that very few fringes were present. The introduction of film altered the fringe pattern, but the addition of an index-matched liquidbrought the fringes back nearly to the original pattern. The same apparatus described above was used to photograph these fringes, except that the curved film holder was replaced by the liquid cell just described. Figure 4 shows the interference fringes for the cell alone with no film and for five cases of film with and without liquid. The fact that the wet-film interference pictures look nearly like the picture of the cell with no film indicates that most of the optical path variation is due to the film surface variation and very little is due to variation of film refractive-index. Film thickness thus appeared to be mainly responsible for the variation in optical path length.

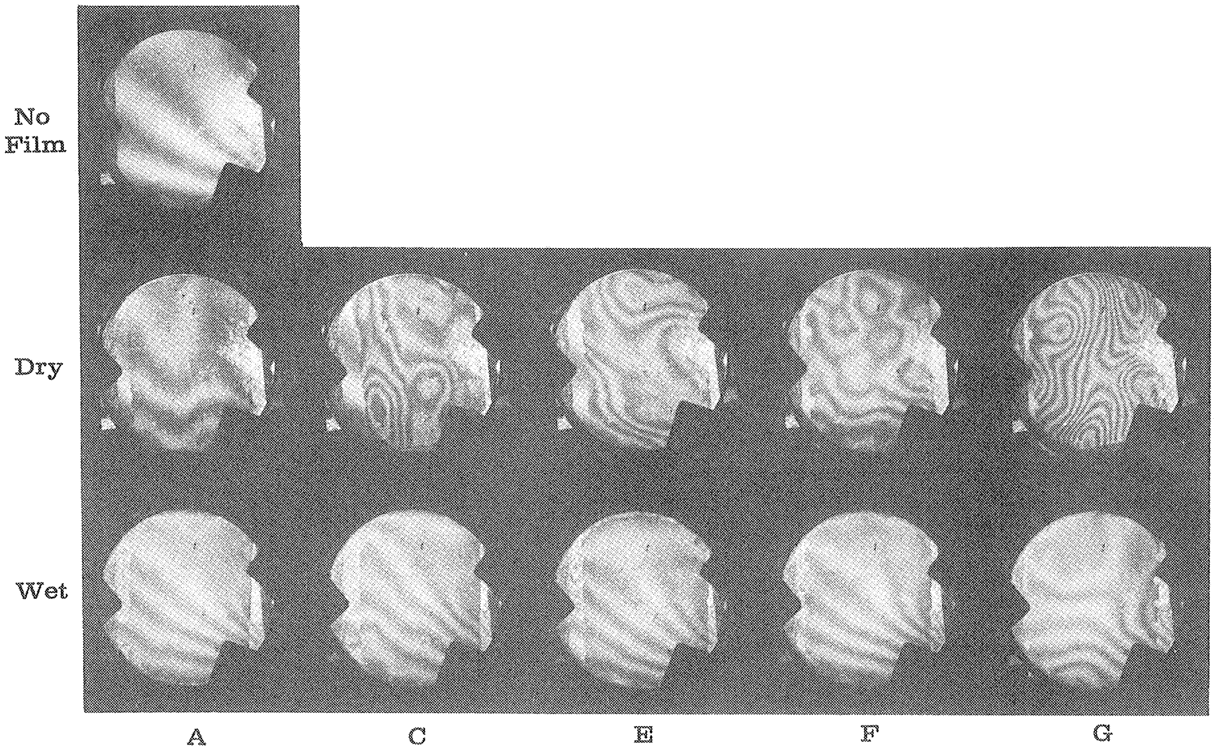

FIG. 4. SURFACE VS. INDEX VARIATION, USING LIQUID GATE

It is noted that more fringes appear in the wet film than in the "no-film" photographs. This is due to the shorter effective wavelength in the liquid. Also the fringe count in the case of dry film is one-third of that which appears in interference between the front and back surfaces of the film of the first test.

3
DISCUSSION OF RESULTS

Quantitative measurements were obtained by counting fringes linearly over a measured distance on the film-surface-interference photographs. This permitted quantitative representations of the light deviation due to wedge, for the various quality ratings. Two values were obtained, one for average deviation and one for maximum deviation. The average deviation was obtained by counting fringes linearly over the interference photograph and dividing the number of fringes by the distance covered in millimeters. A computation was then necessary to express this as average deviation. Maximum deviation was obtained by obtaining the fringe count divided by distance for a small length at the position where the fringe system was the finest.

The formulation used was:

$$D = \frac{(\mu - 1)}{2\mu} \cdot \frac{n}{S}$$

where

D = deviation angle,

μ = refractive index (1.478),

λ = wavelength of light (0.0005461 mm),

n = fringe count, and

S = distance over which fringes were counted.

Figure 5 shows the average results obtained using eleven different photographs.

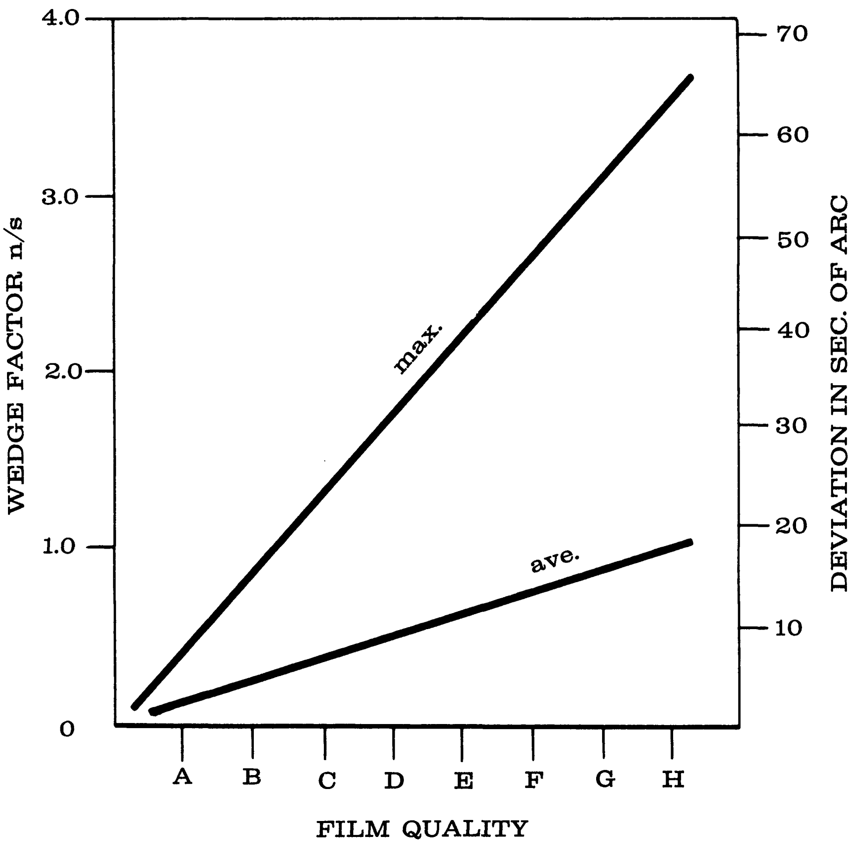

FIG. 5. WEDGE EFFECT IN FILM. From left to right, film quality varies from good to poor.

Since the optical path variation defect was found to be principally due to variation in base thickness, the pattern of fringes obtained in the photographs of Fig. 2 are essentially a topographical map of the optical thickness variation in the film. The space from one dark line to another shows a thickness change represented by:

$$\Delta t = \lambda/2\mu = 0.0005461/2 \times 1.478$$
$$= 0.00018 \text{ mm/fringe}$$
$$= 0.0000073 \text{ in./fringe}$$

where Δt = thickness change. Maximum thickness variations can be obtained by counting fringes and multiplying by the above given thickness change per fringe. On this topographical map:

(1) Parallel lines indicate a slope forming an optical wedge. The finer the line structure, the steeper the slope.

(2) Concentric circles indicate either hills or depressions.

(3) Saddle points usually separate two hills in one direction and two depressions in the 90^o direction.

(4) A hill and a depression are separated by more or less parallel fringes, where the finest line structure occurs at the inflection point.

In order to determine the effect of film-thickness variation during use and measurement, three separate situations must be considered:

Case A: Transmission of light through film.

Case B: Light reflected from both surfaces of film.

Case C: Light reflected from two glass plates having film, film and liquid or no film between them.

Since these three cases are slightly different mathematically, they are treated separately.

Case A (Fig. 6)

In this situation film is in use in a gate which may or may not contain a liquid. It is assumed that light passes through thicker and thinner portions of the film and the optical path difference (OPD) is given by the formula

$$\text{OPD} = (\mu_2 - \mu_1)\Delta t.$$

Case B (Fig. 7)

This is the case where interference takes place between light reflected normally from the front and back surfaces of a piece of film. In this case black lines appear where a path difference between the front and back reflections is a whole number of wavelengths. The formula for change of thickness is

$$\Delta t = n\lambda/2\mu,$$

where n is the number of black (or white) lines counted between points. This applies to the pictures in Fig. 2 and 3.

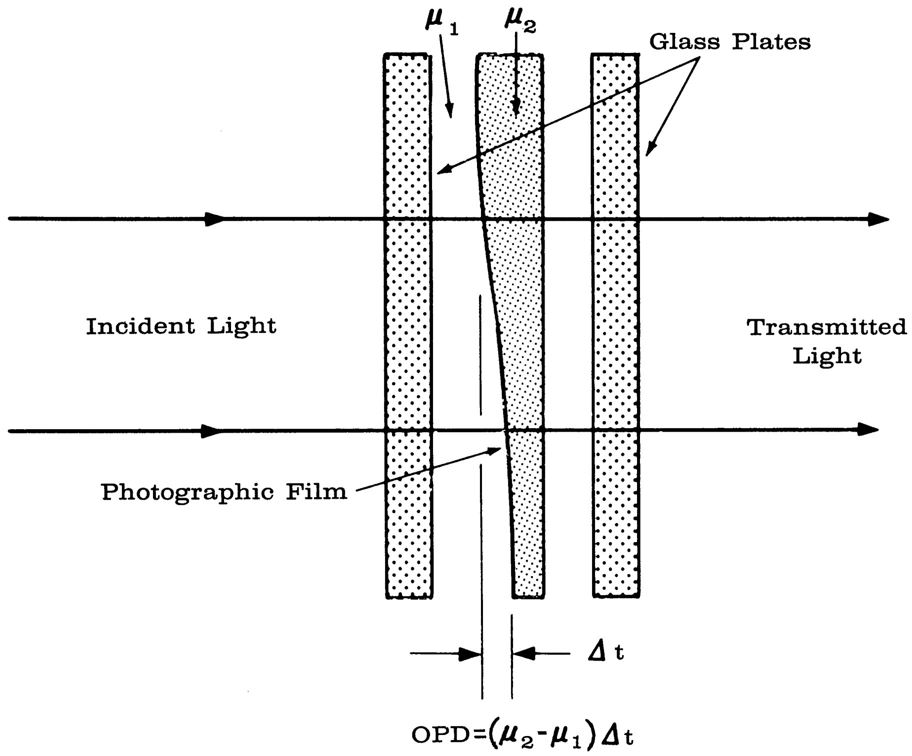

FIG. 6. TRANSMISSION OPTICAL PATH DIFFERENCE. Case A, liquid gate.

Case C (Fig. 8)

In this case, interference occurs due to combining light reflected from the partial mirror surfaces of the two glass plates. One of the reflected rays will have traveled twice through the film and its immersion medium. The formula for optical path difference is:

$$OPD = 2(\mu_2 - \mu_1)\Delta t;$$

and for the number of fringes associated with a change of thickness:

$$\Delta t = n\lambda/2(\mu_2 - \mu_1).$$

From these cases, certain deductions follow. First, upon comparing Case B with Case C (dry cell) it appears that the number of fringes will be different for the same change of film thickness.

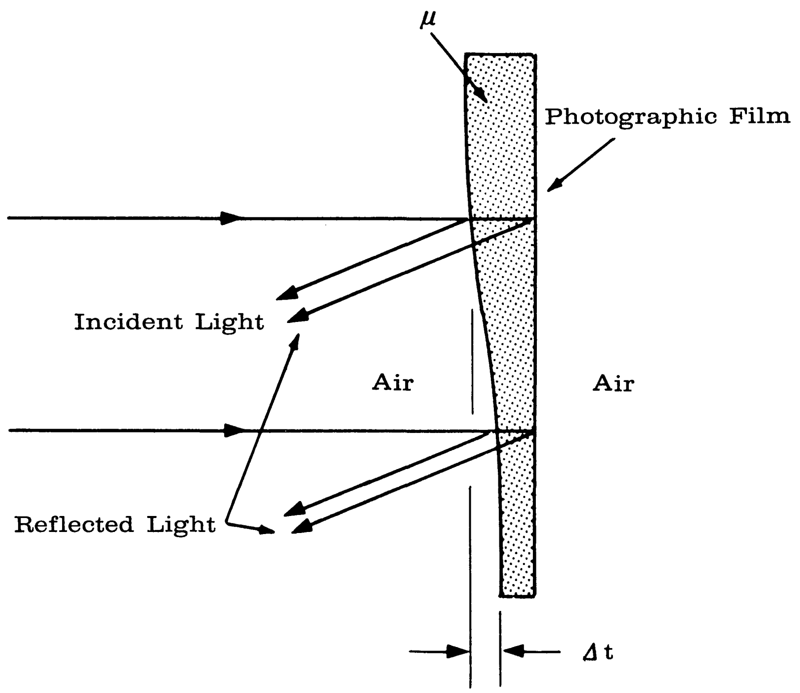

FIG. 7. INTERFERENCE IN PHOTOGRAPHIC FILM. Case B.

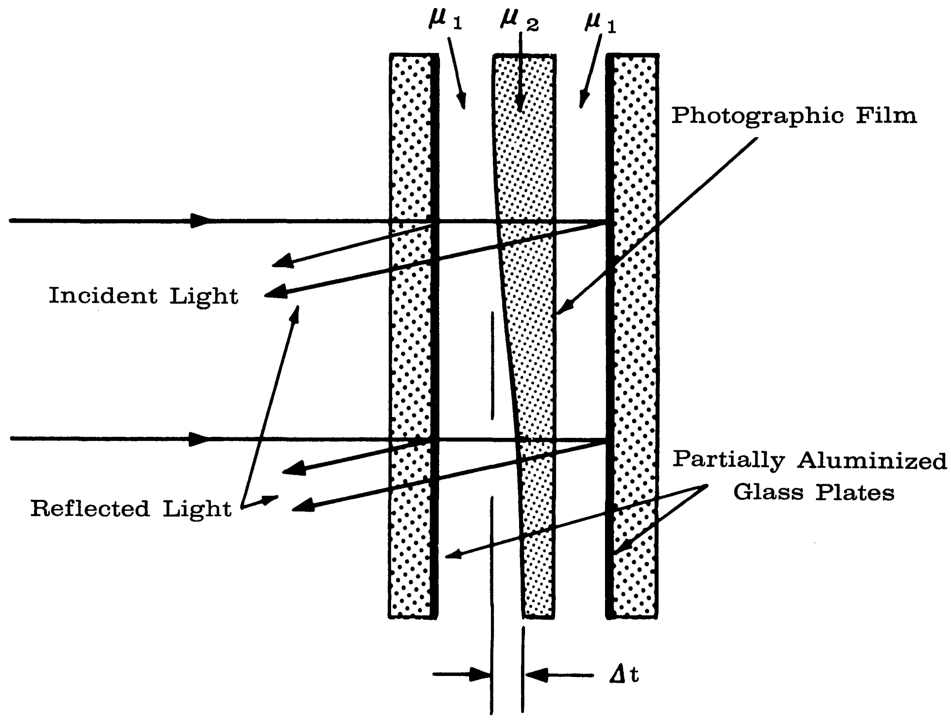

FIG. 8. INTERFERENCE IN LIQUID CELL. Case C.

For Case B, $n_B = 2\mu\Delta t/\lambda$;
for Case C, $n_C = 2(\mu - 1)\Delta t/\lambda$;
therefore, $n_B = n_C\mu/(\mu - 1)$.

This shows that, for $\mu = 1.478$, the number of fringes for Case B is approximately three times the number of fringes for Case C. For this reason there are fewer fringes apparent in the Fig. 4 "dry" cell than in Fig. 3, although the same films were used. Secondly, upon comparing the "wet" cell with the "no film" cell it is noted that more fringes are apparent in the wet-cell case. This is to be expected, since the effective wavelength in the cell is λ/μ_2 which is smaller than the wavelength λ for the same cell in air. This means that we should find nearly 50% more fringes in the wet-cell case due to this effect.

4
PERMISSIBLE LIMITS

In order to select a film having acceptable variations, the Rayleigh limit may be employed. This specifies that no more than one-quarter of a wavelength of light of optical path difference is permissible over the active aperture. OPD due to thickness variations (Δt) of a film (of index μ_2) immersed in a medium (or index μ_1) can be represented by the formula:

$$\text{OPD} = (\mu_2 - \mu_1)\Delta t$$

(Fig. 6). If the Rayleigh limit of a quarter of a wavelength ($\lambda/4$) is used as the maximum allowable departure from coherence, the formula for the maximum allowable thickness variation of the film becomes

$$\Delta t_{max} = \lambda/4(\mu_2 - \mu_1).$$

For film immersed in air and using a green mercury lamp for monochromatic light, the permissible variation in film thickness is approximately 0.0001 mm, a very small variation indeed.

However, film may be immersed in a liquid whose index approximates that of the film (Ref. 3). A plot of the Rayleigh allowable film-thickness variation vs. immersion-liquid index for a film index of 1.478 is given in Fig. 9. The ordinate is also given in terms of number of fringes as counted on an interference photograph of film-thickness variation. (Film thickness per fringe is $t/n = \lambda/2\mu$).

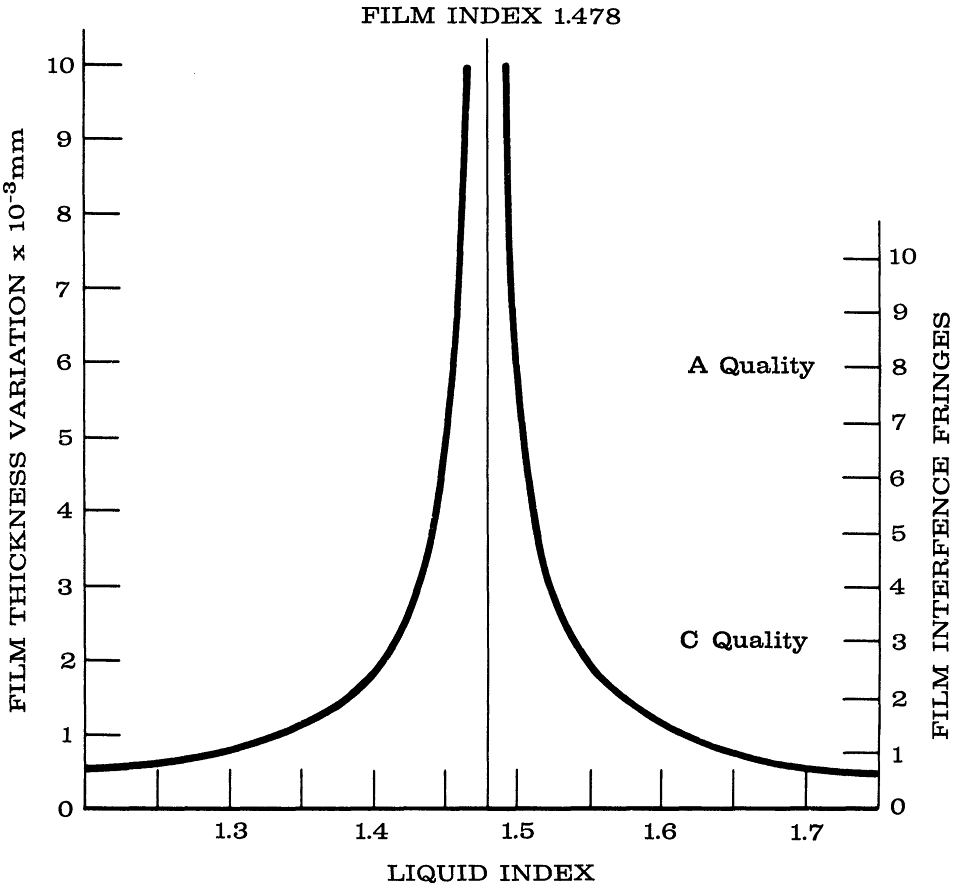

FIG. 9. INDEX-MATCHING DIAGRAM

By counting fringes on the quality chart (Fig. 2) it will be seen that C quality has a maximum of about nine fringes from hill to depression allowing an immersion-liquid index variation from about 1.46 to 1.50. For film in air, a variation of only a half fringe can be tolerated. For film immersed in water (n = 1.33), variation of less than one and a half fringes can be tolerated.

An additional advantage is gained by the use of a liquid gate. Scratches and rough surface present on the film give rise to scattered light. The scattered light from films used in the optical aperture produce loss of contrast in the final image. The use of liquid in a liquid gate fills in the scratches and rough surface, thereby eliminating scratched light from this source.

When an immersion liquid is used, change of phase due to a relief image is eliminated. This phasing under some conditions may be in such a direction as to increase the illumination in the final image. If this happens, the liquid serves to reduce illumination and its use is then classed as a disadvantage.

5
CONCLUSIONS

Through the use of light interference measurements, change in film-base thickness is found to be the principal cause of variations of optical path through film. Variations between films are distributed over considerable differences. A high degree of excellence in manufacture is necessary to use film in an air aperture and maintain coherence of light within the Rayleigh limit. The use of a liquid gate with film has both advantages and disadvantages. The advantages are:

(a) Reduced light-phase variation due to thickness variation;
(b) Film easily retained in a plane by a glass plate cell; and,
(c) Reduction of noise due to scratches and rough surface.

The disadvantages are:

(a) Liquid-handling difficulties, and
(b) Elimination of phasing due to relief images.

Some lack of match between liquid and film may be allowed without exceeding the Rayleigh limit for a particular film.

It is evident that the sampling is too small to prove any trend conclusively. Enough evidence is available, however, to indicate the advisability of pursuing this study further, and to reveal the advantages of expending efforts to achieve a substantial improvement in film quality.

REFERENCES

1. Gabor, D., "Microscopy by Reconstructed Wavefronts," London, Proc. Roy. Soc. (London) A, 1949, Vol. 197, pp. 454-487; Proc. Phys. Soc. (London) B 1951, Vol. 64, pp. 244-255; pp. 449-469.

2. Kirkpatrick, P., and El-Sum, H. M. A., "Image Formation by Reconstructed Wavefronts," J. Opt. Soc. Am., 1956, Vol. 46, pp. 825-831.

3. "Printing Motion-Picture Films Immersed in a Liquid," Part I: "Contact Printing," by Stott, J. G., Cummins, G. E., and Breton, H. E.; Part II: "Optical Printing," by Turner, J. R., Grant, D. E., and Breton, H. E., J. Soc. Motion Picture Television Engrs., October 1957, Vol. 66, pp. 607-615; Part III: "Evaluation of Liquids," by Delwiche, D. A., Clifford, J. D., and Weller, W. R., J. Soc. Motion Picture Television Engrs., October 1958, Vol. 67, pp. 678-686.

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THE EFFECT OF FILM-THICKNESS VARIATIONS ON COHERENT LIGHT by Arthur L. Ingalls. Memorandum of Project MICHIGAN and Technical Memorandum. Oct. 59. 13 p. incl. illus., table, 3 refs.
(Memorandum no. 2831-13-R/2900-88-R)
(Contracts DA-36-039 SC-78801; AF 33(600)-38019; AF 30(635)-2905) Unclassified memorandum

This report describes the experiments which measured perturbations in monochromatic coherent light caused by variations in film thickness, and discusses the results.

The introduction of commercial photographic film into the aperture of an optical system disturbs the coherence of the transmitted light, because of the variations in thickness and refractive index present in the film. Such variations in film may be made visible, as contour lines, by light interference between the front and back film surfaces. Photographs of the interference pattern were measured, and calculations of light-path variations made. A qualitative analysis showed that film-base thickness-variation was primarily responsible for deterioration of coherence. Formulas are given which show the effect of film variations on coherent light for both use and measurements, and figures are included which show the distribution of film quality.

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