PAR 234

MTF Exposure Device

18 March 1965

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PROJECT AUTHORIZATION REQUEST

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SUBJECT: MTF Exposure Device

TASK/PROBLEM

1. Develop and fabricate a device to expose sine-wave test patterns upon photosensitive materials as a step in the process of measuring MTF of the materials.

PROPOSAL

2. Introduction: We propose to develop subassembly designs and to design, fabricate and test an instrument of moderate size to expose sine-wave target patterns upon photosensitive materials for use in measuring Modulation Transfer Function (MTF) of that material. The technique described by R. L. Lamberts[1] will be the basis of the proposed instrument.

3. Approach:

a. The objective lens proposed for the instrument is a 40mm E.F., f/2.8, narrow field Petzval-type lens with a field flattener and fluorite elements. This lens design has shown very excellent performance with nearly perfect chromatic correction. One sample of the lens has produced MTF in the aerial image, as scanned with a one micron wide slit in a microphotometer, as shown in Table 1. The performance indicated should not be considered as a guarantee but as indicative of the design capability. As described by Mr. Lamberts, a high-quality cylindrical lens is to be placed in front of this lens to convert the variable-area test objects into a variable-intensity exposure on the film sample.

b. Consideration will be given to using the 40mm E.F. lens described in paragraph 3 at 50:1 reduction from the test objects to the exposed image to provide test exposures having 2.5 to 400 cycles/mm. With this arrangement, it appears practical to mount the test object holder, the lens and the film sample holder upon a common rigid beam (about seven-feet long). The beam can be shock mounted to isolate that critical portion

[1] R. L. Lamberts, Jl. Opt. Soc. Am., 49, 425 (1959): Reprint attached.

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Table 1

Performance of 40mm E.F. Petzval/Fluorite Lens Sample

Spatial Frequency	MTF*		
	Blue	Green	Red
50 cycles/mm	.82	.80	.79
100 cycles/mm	.72	.68	.66
200 cycles/mm	.56	.51	.48
300 cycles/mm	.42	.36	.31
400 cycles/mm	.30	.21	.12

* Common Focal Plane.

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of the instrument from building vibration.

c. The proposed lamphouse for the instrument will provide a condenser lens to illuminate a test object area about 3.75 inches x .50 inches. The light source will be a tungsten filament lamp with a high-diffusion envelope, such as the General Electric Photoenlarger Lamps, Code PH/211, Code PH/212, or Code PH/213. The PH/212 lamp will provide test object luminance of about 6,000 foot-lamberts (envelope luminance). Means will be provided to reduce the test object luminance by 2.5 to 3.0 decades below that level. Insertion of diffusors, aperture plates, change of lamp position, etc., will be considered for this control. A shutter system providing precise exposures times from 1/30 second to 110 seconds will be provided. Two filter wheels and a position for the manual insertion of filters will be provided. It is expected that one filter wheel will contain neutral density "Inconel" filters of approximately 0.0, 0.3, 0.6 and 0.9 to permit convenient production of an exposure series of the sine-wave test patterns. The second filter wheel can be used for color filters to simulate various photographic situations such as red, green, and blue separation filters for color photography, simulation of Wratten 12 filter plus daylight illumination used for black-and-white aerial photography, etc.

d. In the proposed camera arrangement, the various test patterns are exposed upon the film sample sequentially. After each exposure, the test object must be changed and the film sample advanced for the next exposure. We propose to build and test breadboards of:

(1) Test object changer mechanism,

(2) Mechanism to hold and advance 35mm x 12-inch film samples, and

(3) Adjustable luminance light source system,

before starting design of the complete instrument.

e. The instrument will have provision for making microphotometer measurements of the modulation obtained in the aerial image formed by the objective-cylinder lens assembly for each of the test targets delivered with the instrument. These calibration measurements will be made before delivery of the instrument and are expected to hold for an extended period of time.

f. The instrument controls and sample handling will be carefully designed for convenient operation in darkroom conditions. In order to permit the most convenient sample handling, it is proposed to completely enclose the light source and optical path of the instrument and to leave the sample open to room conditions during the exposure cycle. This has proven to be the most convenient arrangement for similar film testing devices, such as sensitometers and the like.

PROGRAM OBJECTIVE

4. Phase 1: Develop, fabricate and test one (each) breadboard model of:

a. Test object changer mechanism.

b. Mechanism to hold and advance 35mm x 12-inch film samples.

c. Adjustable luminance light source system.

5. Phase 2: Design, fabricate and test one prototype instrument to expose sine-wave test patterns on photosensitive materials as required for measuring MTF values for those materials. Design drawings and sketches will be prepared as required by the contractor's model shop to complete fabrication, assembly and test.

SCHEDULE

6. A tentative schedule covering major phases of effort is shown in Figure 1. The time span indicated to complete Phase 1 of the subject program is based on actual start of work. Upon approval to proceed and/or start of work, schedule will be reviewed and necessary changes reported as required. Phase 2 schedule will be reviewed at or near the completion of Phase 1 and necessary changes will be reported.

TENTATIVE SCHEDULE

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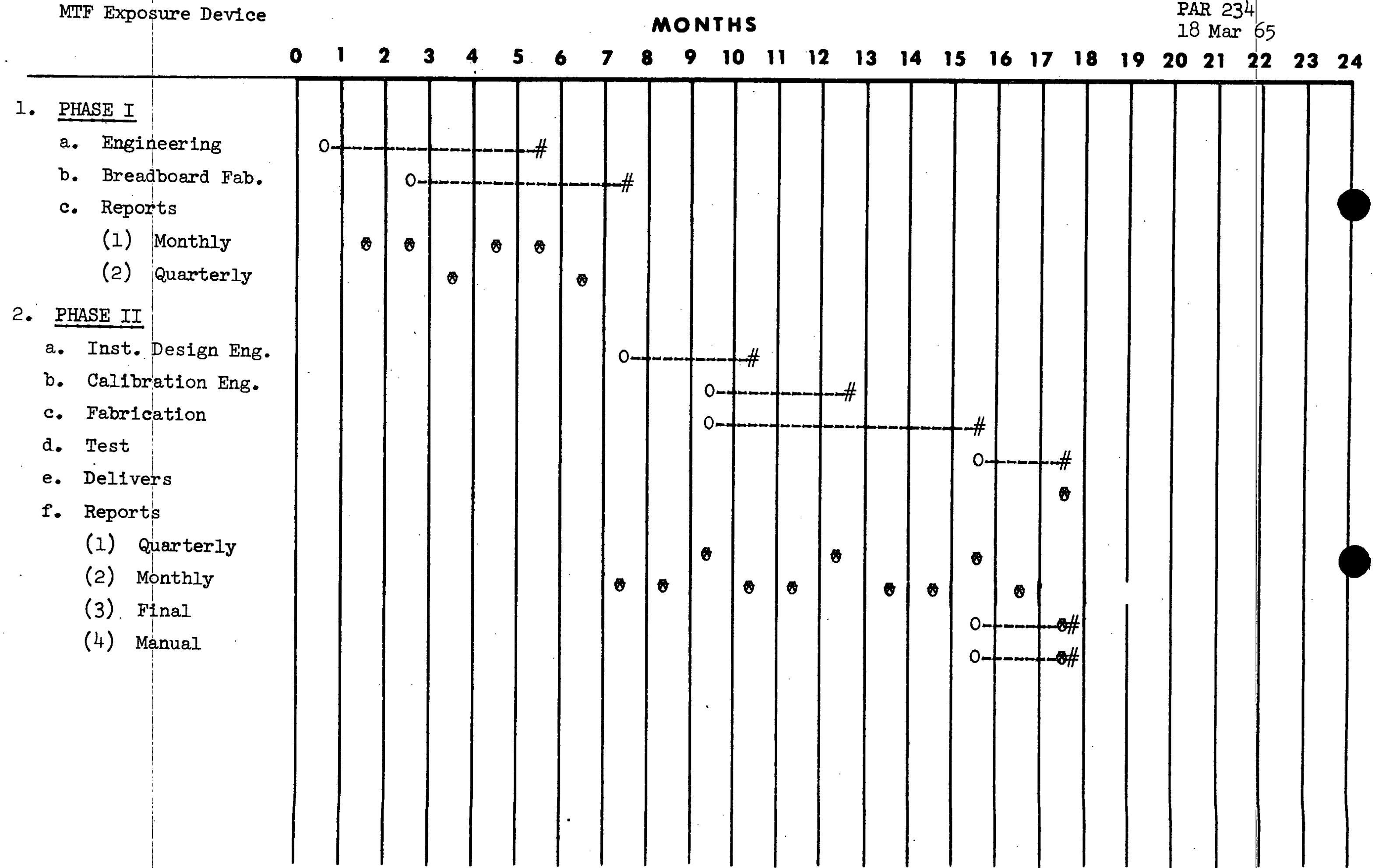

Figure 1

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Reprinted from JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, Vol. 49, No. 5, 425–428, May, 1959
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Measurement of Sine-Wave Response of a Photographic Emulsion*

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(Received November 13, 1958)

A method for experimentally determining the sine-wave response of a photographic emulsion is described. It consists in determining the sine-wave response of a lens, using the lens to photograph a sinusoidal test object on the emulsion under test, determining the response of the lens-emulsion combination, and dividing out the response of the lens. Since sine-wave response is defined in terms of relative exposure in the emulsion, it should be substantially independent of development conditions and the exposure level when adjacency effects are absent. This expectation has been confirmed experimentally. It is also shown that the sine-wave response of a lens and the response of an emulsion can be combined to predict the characteristics of the lens-emulsion combination.

THE application of communication theory to the microstructure of optical images has provided not only a better theoretical understanding of the process of image formation but new means for the practical measurement of images as well. This approach is very useful in studying the photographic system because if one knows the sine-wave response or transfer function of each component of the system, the sine-wave response function for the complete system is simply the product of the individual response functions. In other words, it becomes possible to "engineer" the microstructure of the photographic system.

However, until the present time, the majority of the experimental work has been done with the response characteristics of lenses and comparatively little work has been reported for the sine-wave responses of emulsions. A single response curve for Kodak Panatomic-X Film was reported by Ingelstam, Djurle, and Sjögren.[1]

Since the sine-wave response function is equivalent to the Fourier transform of the spread function, the sine-wave response and the spread function represent to a considerable extent the same data—strictly so in this instance, where the emulsion spread function can be assumed to be symmetrical.[2] It is then theoretically possible[3] to obtain the desired data by using either a line image or an edge image to measure the spread function, or by using sinusoidal patterns to measure the sine-wave response. The selection of the method is a matter of convenience, and there appear to be several distinct advantages to using the latter method: (1) The sinusoidal images can be made to cover an extended area of the film so that random fluctuations arising from granularity can be averaged out, thereby increasing the accuracy of measurement. (2) Since the resulting data are in the form of a sine-wave response function, the effect of the system used to put the images onto the film can be divided out of the system by a simple procedure.

The principle of the convolution of images assumes the simple additivity of spread functions. For this reason, the spread function or the sine-wave response of an emulsion must be expressed in terms of the light falling onto the film or the exposure of the film rather than in terms of the density or transmittance of the developed image. The emulsion is then used as its own photometer; a given density in the developed image is taken to represent a certain exposure given to the emulsion. The line spread function of an emulsion will then be defined as the one-dimensional distribution of light or exposure within the emulsion if an infinitely narrow line of light were to be imaged onto the film. The distance coordinate expresses the distance from this line along the emulsion surface. Since an emulsion is almost always utilized as a plane, it is justifiable from the viewpoint of application to disregard the variation of exposure as a function of depth in the emulsion.

Figure 1 shows a simplified sketch of the experimental setup used for making sine-wave response exposures. A test object of the form shown in the enlarged scale is imaged by means of a high-quality objective lens. Since the illuminance along the scanning slit must be constant to give a trace like a variable-density motion-picture sound track, a cylindrical lens is inserted in front of the objective lens to smear the image in a

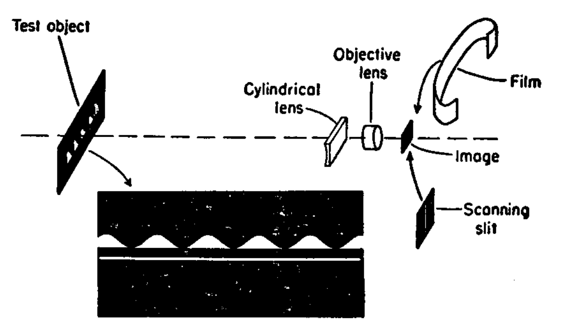

FIG. 1. Schematic drawing of apparatus used for recording sinusoidal image on film or (alternatively) scanning it. A sketch of the test-object pattern is shown on an enlarged scale.

* Communication No. 1988 from the Kodak Research Laboratories. Presented at the Washington Meeting of the Optical Society of America, March 27–29, 1958, under the title, "Measurement of Sine-Wave Response and Spread Function of a Photographic Emulsion."

[1] Ingelstam, Djurle, and Sjögren, J. Opt. Soc. Am. 46, 707 (1956).

[2] R. L. Lamberts, J. Opt. Soc. Am. 48, 490 (1958).

[3] Lamberts, Higgins, and Wolfe, J. Opt. Soc. Am. 48, 487 (1958).

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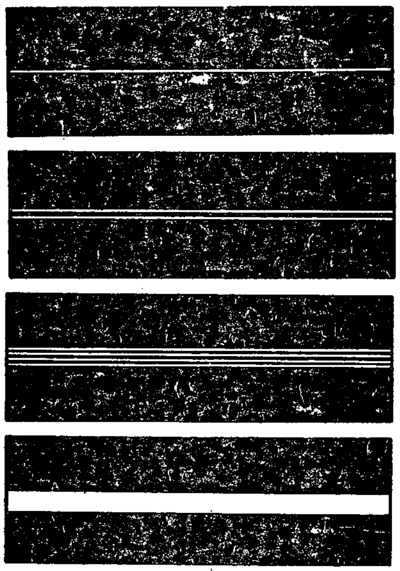

FIG. 2. Test-object patterns used to calibrate the microdensitometer. Each pattern produces an exposure of twice the one above.

vertical direction. As was described in a previous paper,[2] it is possible on the lens bench in these laboratories to scan an aerial image photoelectrically with a narrow slit, and also to replace this scanning unit with a camera unit so that the photographic emulsion falls into exactly the same position as was previously occupied by the slit. This arrangement makes it possible to determine the modulation of the sinusoidal patterns which fall onto the emulsion.

The test object, as shown on an enlarged scale at the bottom of Fig. 1, has a slit running parallel to the length of the pattern. This slit is used to reduce the contrast or modulation within the aerial image for the lower spatial frequencies, because without it, the very large exposure difference resulting between the light and the dark portions of the image would exceed the latitude of the film and make photographic photometry impossible. For spatial frequencies higher than about 50 lines/mm, it was not found necessary to use such slits since the lens itself reduced the exposure amplitude by the necessary amount.

The objective lens was a 40-mm, $f/2.0$ lens of very high quality. This lens was operated at an aperture of $f/2.8$, where the quality was sufficiently high to make possible imagery up to a spatial frequency of 400 lines/mm. Since this lens was not apochromatic, it was necessary to use a restricted spectral region. All data shown in this paper were determined with green light (Kodak Wratten Filter No. 61).

A -4.0 diopter cylindrical lens was sufficient to smear the image adequately. By reason of this smearing, the width of the clear portion in the test object determines the illuminance in the image. With this principle as a basis, a series of calibrating test objects was prepared by printing a given line onto Kodalith Plates to produce one slit, two slits, four slits, and the equivalent of eight slits, as shown in Fig. 2. In like manner, a second series was also prepared with each slit $\sqrt{2}$ times as wide as those in the first series. These provided a calibration with a range of log E from 0 to 1.05 in increments of 0.15. These calibrating slits have advantages over ordinary neutral densities in that they have the same spectral and light-scattering characteristics as the sinusoidal test objects.

Before the sinusoidal patterns were photographed onto the emulsion, the system was analyzed photoelectrically to determine the modulation of the aerial image for each spatial frequency. The point of best focus was chosen to be the point of maximum amplitude for the 100-line/mm frequency in the aerial image. At this focal setting, modulation values for each spatial frequency were determined and tabulated.

To assure correct focus of the camera, a 100-line/mm sinusoidal pattern was likewise photographed at a series of focal positions on a very fine grained emulsion. These images were then scanned with the microdensitometer to determine the focal position giving the maximum amplitude in the developed image.

With the camera thus in correct focus, each member of the series of sinusoidal test objects, as well as the series of calibration slits, was individually photographed on the film to be tested. The camera was made to space exposures closely enough so that all the calibrating and sinusoidal exposures could be made within about $1\frac{1}{2}$ in., thereby minimizing any processing variations. Since all the exposures were made for the same exposure time, errors caused by reciprocity failure were eliminated.

The processed film was then scanned with a microdensitometer.[4] The density patches obtained by photographing the calibration slits were first scanned to

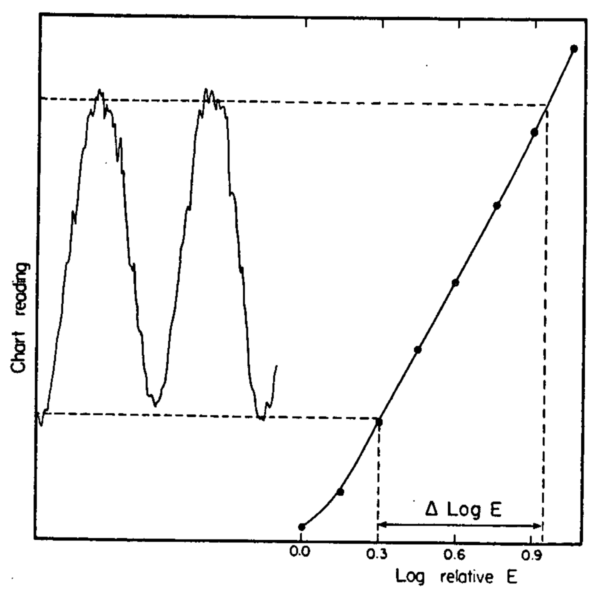

FIG. 3. Microdensitometer trace of sinusoidal image and characteristic curve of emulsion used to record the image, showing how the trace is interpreted in exposure terms.

[4] J. H. Altman and K. F. Stultz, Rev. Sci. Instr. 27, 1033 (1956).

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provide a calibration of the microdensitometer itself in terms of exposure in the image. It was then possible to draw up a calibration curve of the microdensitometer chart reading as a function of log exposure in the image, as is shown in Fig. 3.

The scan of each spatial frequency of sinusoidal patterns was then examined to determine the maximum and minimum values on the recording paper. Values of $\log E_{\max}$ and $\log E_{\min}$ were then determined by using the calibration curve just described. We can write

$$\Delta \log E = \log E_{\max} - \log E_{\min} = \log(E_{\max}/E_{\min}).$$

The modulation of the photographic system consisting of the test object, the lens, and the film is, by definition,

$$\frac{E_{\max}-E_{\min}}{E_{\max}+E_{\min}}=\frac{\dfrac{E_{\max}}{E_{\min}}-1}{\dfrac{E_{\max}}{E_{\min}}+1}.$$

This expression was evaluated readily from the antilogarithm of $\Delta \log E$.

To obtain the sine-wave response of the film alone, the values so obtained were divided by the modulation values measured for the aerial image by the photoelectric scan described earlier.

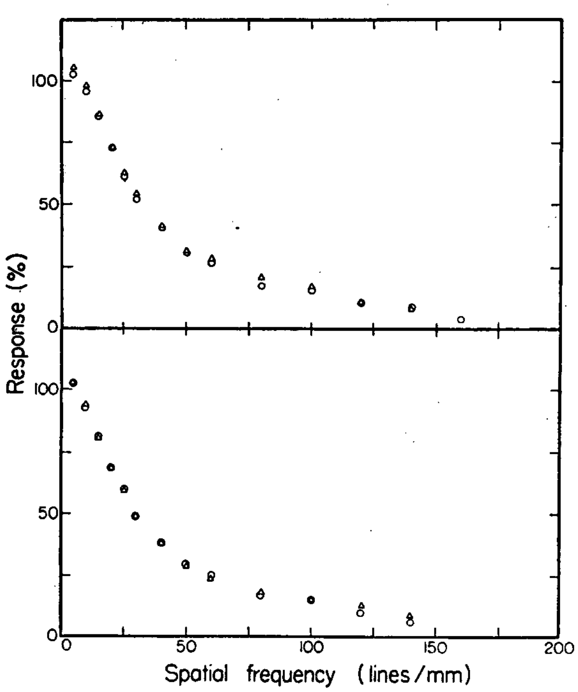

FIG. 4. Upper graph: Sine-wave response data for Eastman Plus-X Panchromatic Negative Film, Type 4231, exposed behind a Kodak Wratten Filter No. 61 and developed in Kodak Developer D-19 for (○) 2 min and (Δ) 10 min. Lower graph: Similar data for a development time of 4 min and exposures to give net densities of (○) 0.35 and (Δ) 1.70.

RESULTS

The sine-wave response of Eastman Plus-X Panchromatic Negative Film, Type 4231, is shown in Fig. 4. In the upper graph, the circles represent the response derived from a sample developed in Kodak Developer D-19 for 2 min at 68°F while the triangles represent the response for a development time of 10 min.† The developer was agitated vigorously to reduce adjacency effects. It is apparent that there is good agreement between the two curves in spite of the differences in development time. The slight rise of the curve above 100 percent for low frequencies can very probably be attributed to adjacency effects.[5] Where high-exposure regions are adjacent to low-exposure regions, there is an accentuation of density differences compared with those between large areas receiving comparable exposures. This is exemplified by the Eberhard effect. The present data show that curves for a given emulsion with moderate differences in their low-frequency rise can usually be matched closely for the entire region of higher frequencies by a simple ratioing of the ordinates. Likewise, it should be pointed out that the amount of bromide in the developer will tend to control the amount of adjacency effects. The higher the existing concentration, the smaller will be the effect of the bromine liberated in processing. Although a detailed study of adjacency effects was not made, it is apparent that sine-wave response techniques have possibilities for appraising these effects.

Exposure time likewise has little effect on the sine-wave response, as can be seen from the lower graph of Fig. 4. In this case the exposures were such as to give an average density in the sinusoidal-pattern exposures of 0.35 for the circles and 1.70 for the triangles when the films were developed in D-19 for 4 min.

The type of developer likewise appears to have little, if any, effect upon the emulsion sine-wave response. Measurements made for films developed in Kodak Developer D-76 showed essentially the same curve as for D-19 except for a difference in rise attributable to adjacency effects.‡

Figure 5 shows a comparison of the sine-wave response curves for several Kodak films. The extreme condition is represented by the fine-grain experimental documentary recording film (curve 4). This film is almost as fine-grained as Kodak High Resolution Spectroscopic Plates, and the flatness of this curve confirms

† The data presented in this paper are representative of the emulsions manufactured at the time of writing. However, it must be recognized that the characteristics of products of the same name may vary within manufacturing tolerances and may change significantly as improvements are effected.

[5] C. E. K. Mees, *The Theory of the Photographic Process* (The Macmillan Company, New York, 1954), revised edition, pp. 1031–1038.

‡ From the early data, reported in the oral paper, it appeared that the form of the sine-wave response curve changed in going to fine-grain developers such as D-76. A more thorough recheck of these characteristics, however, showed no differences that seemed to be experimentally significant.

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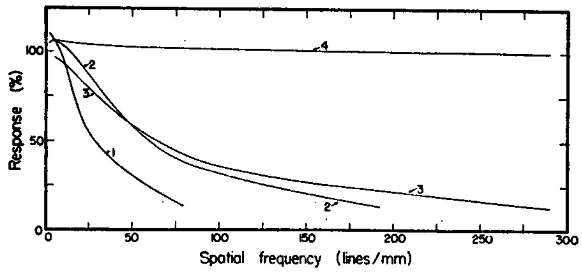

FIG. 5. Sine-wave response of the following Kodak films developed in the following Kodak developers: (1) Tri-X, DK-50, 5 min; (2) Panatomic-X, D-19, 3 min; (3) Micro-File, D-11, 4 min; (4) Experimental document-recording, DK-50 (1:10), 10 min. Exposed through Kodak Wratten No. 61 Filter.

a general observation by users of such emulsions that the image quality is much superior to practically any optical system that can be used with them.

It should be noted that the errors arising from the finite slit widths of both the microdensitometer and of the photoelectric unit of the lens bench tend to compensate for each other in the final result. The 1-μ slit, as used for the photoelectric unit of the lens bench, is of the same width as the slit generally used with the microdensitometer and with which the present samples were scanned. The slit in the photoelectric scanning unit gives values of response that are lower than the true values. Likewise, the microdensitometer has a tendency to give values of response that are slightly lower than the true values obtained with an infinitely narrow slit. Since the microdensitometer data are divided by the lens-bench data, these slit effects tend to cancel each other.

COMBINATION OF LENS AND FILM CHARACTERISTICS

To illustrate how the emulsion characteristics can be combined with the lens characteristics and to show how the combined data can be used to predict the density-distance relationship in the image of an edge, the following demonstration was prepared:

By using Plus-X emulsion and with the lens on the lens bench placed a few thousandths of an inch away from the position of best focus, an edge with an illuminance ratio of about 4:1 was photographed and the developed image was scanned on the microdensitometer. The sine-wave response of the lens at this focal position was then determined by scanning sinusoidal test objects of 100% modulation. By making the exposures with the lens slightly out of focus, the curve of sine-wave response was made to have a different shape from that used in obtaining the response of the emulsion. The new response curve was multiplied by the response curve of the emulsion obtained as described in the preceding section, and the Fourier transform was made of the combined response to obtain the spread function of the lens-film combination. This spread function was then integrated into an edge distribution,[3] the required amount of flare light was added to give the correct contrast, and, finally, the characteristic curve of the emulsion was applied to give the density-distance function. A comparison of the measured and calculated edge curves is shown in Fig. 6. The smooth curve was

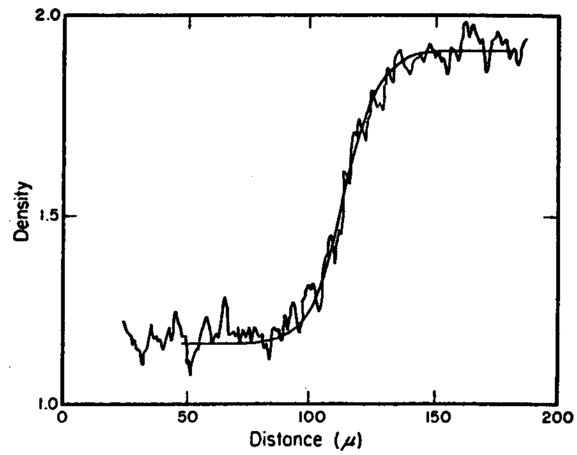

FIG. 6. Comparison of computed edge trace for a certain lens-film combination (smooth curve) with experimental trace ("grainy" curve).

calculated and the "grainy" curve was made with the microdensitometer. The good agreement between the measured and the calculated curves demonstrates that the shape of the edge trace for a lens-film combination can be predicted from the sine-wave response data.

CONCLUSIONS

It is possible to use the techniques described here for measuring the sine-wave response of an emulsion with good accuracy and reproducibility. Except for adjacency effects, the sine-wave response of an emulsion tends to be independent of exposure level and processing conditions. The sine-wave response function of the emulsion can be used to predict the characteristics of a lens-film combination if the sine-wave response of the lens is also known.

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