Approved For Release 2001/04/02 : CIA-RDP78B04747A000200010030-6

[redacted]

STATINTL

October 8, 1964
HBH:bjs-431

To: [redacted]

From:

Subject: The Relation between Average Photographic Density and Transmittance for Four Cases of Interest.

STATINTL

cc: [redacted]

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Introduction

The analysis of density traces of photographic transparencies raises a special problem when it is desired to determine the "average density". The true average density, which is the average level of the densitometer trace, is in general not equal to the value of density that is approached when the area of the scanning aperture is increased. This latter density is determined only by the average transmittance.*

It is the purpose of this memorandum to find the relation between the average density ($\overline{D}$) and the average transmission ($\overline{T}$) for four cases of interest:

(1) Square wave
(2) Sawtooth in transmittance
(3) Sine-wave in transmittance
(4) Noise due to photographic grain

The first three cases will be treated by determining the spatial averages:

$$\left.\begin{aligned} \overline{D} &= \frac{1}{X}\int_0^X D(x)\,dx \\ \overline{T} &= \frac{1}{X}\int_0^X T(x)\,dx \end{aligned}\right\} \qquad (1)$$

where: $D(x) = -\log T(x)$

For these three cases, the transmittance functions are periodic and the range X will be chosen as one period. For the last case (4), a simple statistical model will be used, which consists of a gamma distribution for the probability density function of photographic density.[1]

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* It will be understood that "transmittance" will always mean intensity transmittance.

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Low Contrast Approximation

Before examining the four cases mentioned above, it will be worth while to compare $\bar{D}$ with $\bar{T}$ when the density fluctuations from the mean are small. The density can be written:

$$D(x) = \bar{D} + f(x) \quad (2)$$

where $f(x)$ has zero mean. Eqs. (1) and (2) yield:

$$\bar{T} = \frac{1}{X} 10^{-\bar{D}} \int_0^X 10^{f(x)} dx \quad (3)$$

For small $f(x)$ the integrand can be expanded:

$$T = 10^{-\bar{D}} \left[1 - (\ln 10)\, \overline{f(x)} + \frac{1}{2} (\ln 10)^2\, \overline{f^2(x)} - \dots \right] \quad (4)$$

As the fluctuations become zero, Eq. (4) becomes:

$$\bar{D} = -\log \bar{T} \quad (5)$$

Since $\overline{f(x)} = 0$ it is necessary to retain the $\overline{f^2(x)}$ term to obtain the next higher order approximation. The average $\overline{f^2(x)}$ is commonly known as the variance (σ_D^2).

$$\bar{T} = 10^{-\bar{D}} \left[1 + \frac{1}{2} (\ln 10)^2 \sigma_D^2 \right] \quad (6)$$

Taking the log of both sides:

$$\epsilon = \left(\frac{\ln 10}{2} \right) \sigma_D^2 \simeq 1.15\, \sigma_D^2 \quad (7)$$

where $\epsilon\ (\equiv \bar{D} + \log \bar{T})$ is a measure of the error within which $\bar{D}$ and $-\log \bar{T}$ can be interchanged.

Square Wave

The square wave is defined for one period (X) to be:

$$T(x) = \begin{cases} T_1 & (0 \le x < \frac{X}{2}) \\ T_2 & (\frac{X}{2} \le x < X) \end{cases} \quad (8)$$

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Evaluation of ϵ from Eqs. (1) and (8) yields:

$$\epsilon = \log \cosh\left(\frac{\Delta D}{2 \log e}\right) \qquad \left(\Delta D \equiv \left|\log \frac{T_1}{T_2}\right|\right) \tag{9}$$

For low contrast (small ΔD) Eq. (9) gives:

$$\epsilon = \left(\frac{\ln 10}{8}\right)(\Delta D)^2 \simeq 0.288\,(\Delta D)^2 \tag{10}$$

At high contrast (ΔD becomes large) an expansion of Eq. (9) yields an asymptote for ϵ:

$$\epsilon = \frac{1}{2}\Delta D - \log 2 \simeq \frac{1}{2}\Delta D - 0.301 \tag{11}$$

The dependence of ϵ on ΔD (Eqs. (9) and (11)) is shown in Figure (1).

<u>Sawtooth</u>

The sawtooth wave is defined for one period (X) to be:

$$T(x) = \left(\frac{T_2 - T_1}{X}\right)x + T_1 \qquad (0 \le x < X) \tag{12}$$

Combining Eqs. (1) and (12) yields:

$$\epsilon = \log\left[\frac{e\,(1+\xi)\,\xi^{\frac{\xi}{1-\xi}}}{2}\right] \tag{13}$$

where: $\xi = 10^{\Delta D}$ $\qquad \left(\Delta D \equiv \left|\log \frac{T_1}{T_2}\right|\right)$

For low contrast Eq. (13) gives:

$$\epsilon = \left(\frac{\log 10}{24}\right)(\Delta D)^2 \simeq 0.0959\,(\Delta D)^2 \tag{14}$$

At high contrast the value of ϵ from Eq. (13) approaches a constant:

$$\epsilon = \log\left(\frac{e}{2}\right) \simeq 0.133 \tag{15}$$

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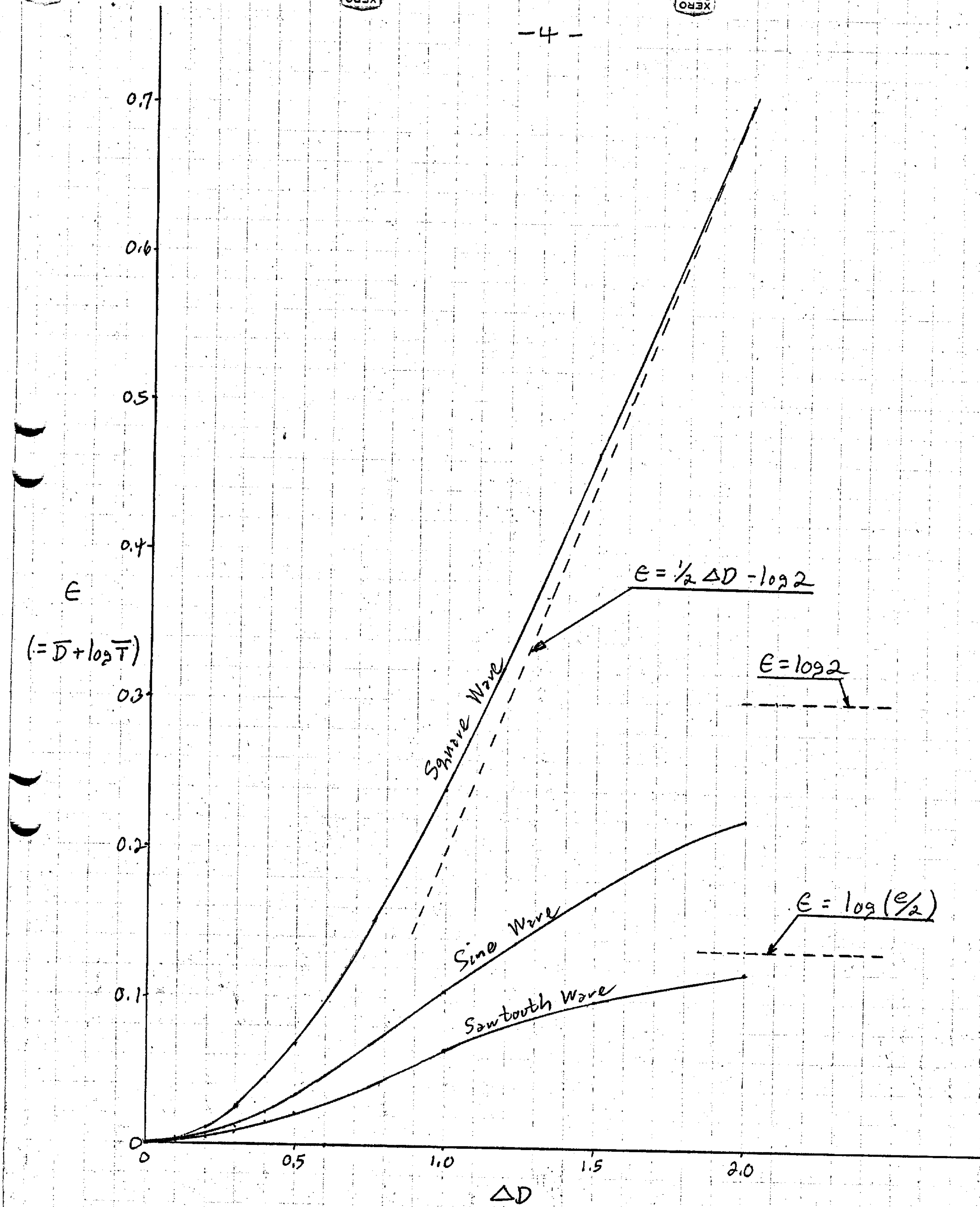

Fig. [illegible] Dependence of Error on Density Difference

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The dependence of ϵ on ΔD (Eqs. (13) and (15)) is shown in Figure (1).

Sine Wave

A sinusoidal transmission function can be defined for one period (X) to be:

$$T(x) = \bar{T}\left(1 + \alpha \cos \frac{2\pi x}{X}\right) \qquad (0 \le \alpha \le 1) \qquad (16)$$

Combining Eqs. (1) and (16) yields:

$$\epsilon = \log\left(\frac{2}{1+\sqrt{1-\alpha^2}}\right) \qquad (17)$$

where: $\alpha = \frac{10^{\Delta D} - 1}{10^{\Delta D} + 1}$ (ΔD = peak density difference)

At low contrast, Eq. (17) gives:

$$\epsilon = \left(\frac{\ln 10}{8}\right)(\Delta D)^2 \simeq 0.288\,(\Delta D)^2 \qquad (18)$$

which is the same as the square wave. As the contrast is increased, ϵ approaches a constant:

$$\epsilon = \log 2 \simeq 0.301 \qquad (19)$$

The dependence of ϵ on ΔD (Eqs. (17 and (19)) is shown in Figure (1).

Density Fluctuations due to Grain

The determination of values of $\bar{D}$ and $\bar{T}$ for a noisy densitometer trace will not be carried out as spatial averages since the noise is the result of a random process. The values will be determined, however, by assuming a probability density function (for either $D(x)$ or $T(x)$) and evaluating the following integrals:

$$\left.\begin{aligned} \bar{T} &= \int_0^1 T\, P_D(T)\, dT \\ \bar{D} &= \int_0^\infty D\, P_D(D)\, dD \end{aligned}\right\} \qquad (20)$$

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where P_T and P_D are the probability density distributions for transmission and density respectively. For the lack of a better distribution, the mathematically convenient "gamma distribution" * is assumed for $P_D(D)'$:

$$P_D(D) = \frac{\lambda(\lambda D)^{r-1} e^{-\lambda D}}{\Gamma(r)} \qquad (0 \le D < \infty) \tag{21}$$

where λ and r are two parameters of the distribution. It is now necessary to find $P_T(T)$ for the above distribution.

The differential probability (dP) can be written:

$$dP = P_D(D)\,dD = P_T(T)\,dT \tag{22}$$

Combining Eqs. (20) and (22) yields:

$$\left.\begin{aligned} \bar{T} &= \int_0^\infty 10^{-D} P_D(D)\,dD \\ \bar{D} &= \int_0^\infty D\,P_D(D)\,dD \end{aligned}\right\} \tag{23}$$

Employing the gamma distribution of Eq. (21) and integrating:

$$\left.\begin{aligned} \bar{T} &= \left(\frac{\lambda}{\lambda + \ln 10}\right)^r \\ \bar{D} &= \frac{r}{\lambda} \end{aligned}\right\} \tag{24}$$

Therefore, the value of ϵ is:

$$\epsilon = r\left[\frac{1}{\lambda} + \log\left(\frac{\lambda}{\lambda + \ln 10}\right)\right] \tag{25}$$

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* Not to be confused with the "gamma function" (Γ).

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where[1]: $r = \left(\frac{\bar{D}}{\sigma_D}\right)^2$; $\lambda = \frac{\bar{D}}{\sigma_D^2}$

Eq. (25) can be written in perhaps a more convenient form:

$$\epsilon = \bar{D}\left[1 - \frac{\ln(1+\eta)}{\eta}\right] \quad (26)$$

where: $\eta = (\ln 10)\frac{\sigma_D^2}{\bar{D}}$

The dependence of ϵ on σ_D (commonly known as granularity for fluctuations arising from grain noise) from Eq. (26) is shown in Figure (2) for different values of $\bar{D}$, along with the low contract approximation of Eq. (7). As $\bar{D}$ becomes large the quadratic curve (Eq. (7)) is approached for all values of σ_D.

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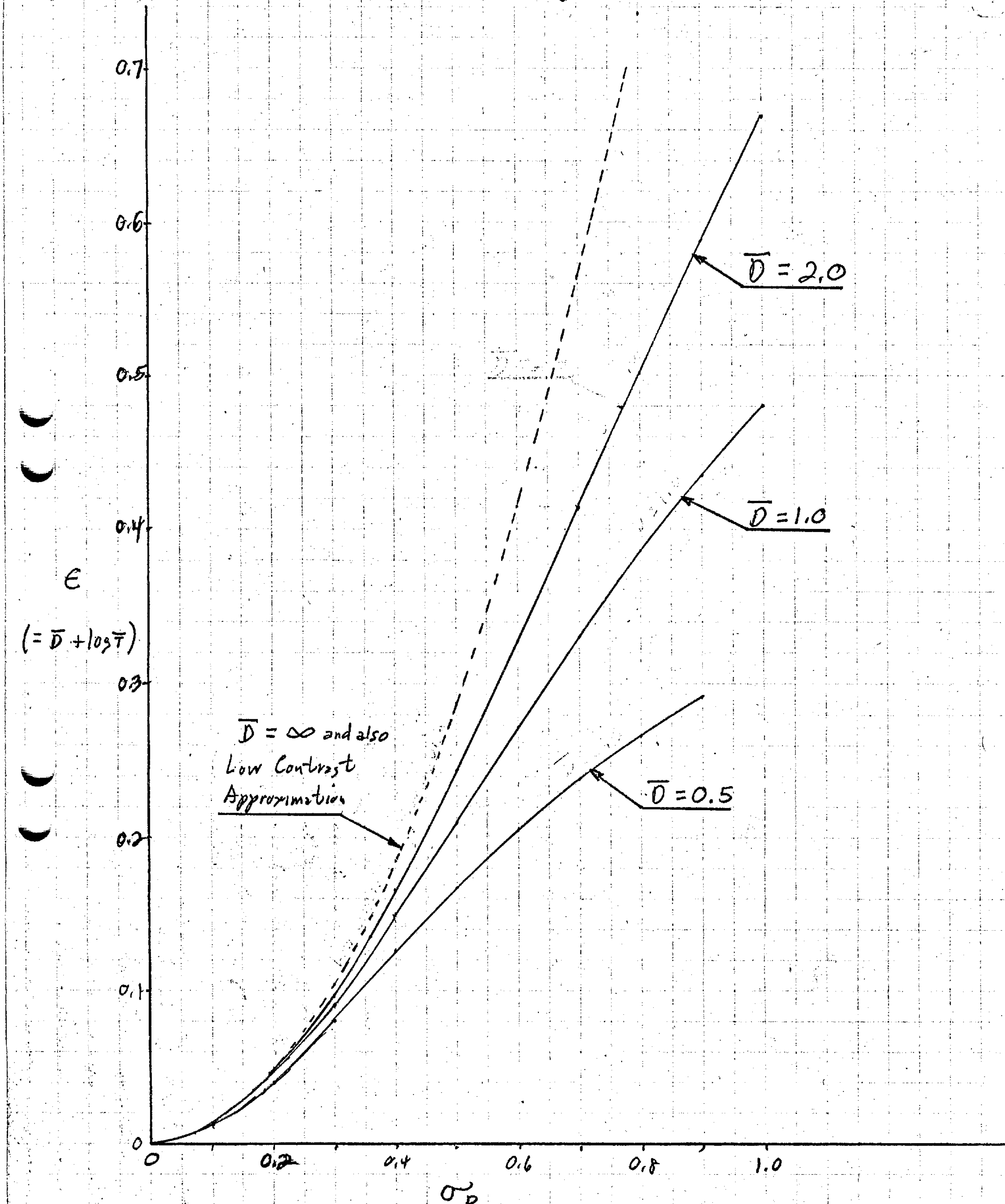

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Reference

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(1) [redacted] "Variance of Transmittance as Obtained from a Gamma Distribution of Density Fluctuations" [redacted] memorandum ET:bb:271 (15 June 1964)

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Form 10% (Rev. 2-53) Approved For [redacted]00200010030-6 STATINTL

FILE:

- ☐ LABORATORY VISITOR
- ☒ TRIP REPORT
- ☐ MISCELLANEOUS REPORT
- ☐ TELEPHONE CALL

STATINTL

CONTACT REPORT

PROJECT NO. 997-112

SUBJECT: [redacted]

DEPT. 72

REPORTED BY: [redacted]

TITLE:

TALKED TO:

DATE OF CALL: October 8, 64

OTHERS ATTENDING CONFERENCE:

PURPOSE OF CALL: To obtain additional data on "Microspot" performance

REFERENCES:

SUMMARIZE RESULT OF CALL OR VISIT—BE BRIEF

FOR ATTENTION OF [redacted]

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The photographic edge produced at [redacted] for project Microcap was scanned using the [redacted] Microanalyzer with the Microspot Aperture to obtain the modulation transfer function of the instrument. This second visit to the [redacted] was made because the data obtained during the previous trip (8-20-64 - 8-21-64) indicated an unexpectedly poor result for the Microspot system.

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The data obtained on this visit did yield a considerably better response curve for the Microspot system than that obtained previously but it did not indicate any significant difference between the standard slit aperture configuration and the Microspot configuration.

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SIGNATURE: [redacted]

DATE:

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Form 104 (Rev. 2-53) Approved For R[redacted]00200010030-6 STATINTL

- ☐ LABORATORY VISITOR
- ☒ TRIP REPORT
- ☐ MISCELLANEOUS REPORT
- ☐ TELEPHONE CALL

STATINTL

CONTACT REPORT

FILE:

SUBJECT: [redacted]

PROJECT NO. 997-112

DEPT. 72

REPORTED BY:

TITLE:

TALKED TO:

DATE OF CALL: October 15, 64

STATINTL

OTHERS ATTENDING CONFERENCE: [redacted]

PURPOSE OF CALL: To evaluate Ansco "Class I" and "Class III" microdensitometers for project Microcap

REFERENCES:

FOR ATTENTION OF [redacted]

SUMMARIZE RESULT OF CALL OR VISIT—BE BRIEF

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Basic models of the [redacted] "Class I" and "Class III" microdensitometers were made available to us at the [redacted] Special Products Plant in [redacted] on October 15, 1964. The microdensitometer evaluation tests developed for project Microcap were conducted on the "Class I" instrument. They could not be performed properly on the "Class III" instrument because the basic instrument is not equipped with a strip chart recorder.

The optical system of the "Class I" instrument is essentially the same as that of the old Model 4 instrument with the exception that the hyperplane oculars have been replaced with [redacted]-designed projective eyepieces. This should, and from the response indicated by the sine wave test charts, does improve the performance of the microdensitometer. The sensitivity of the instrument has been improved somewhat through some modification of the electronic circuitry.

There is still some doubt as to the ability of the instrument to achieve the quoted accuracy. Interferometric techniques were used to determine the accuracy of the screws and of the ways and although accuracy greater than that quoted by [redacted] was apparently achieved, no measurements were made on the stage itself which rests some 10 to 12 inches above the guiding ways. This could lead to a significant degradation of the accuracy of the instrument but would not affect the precision.

The "Class III" instrument appeared to be a very versatile, conviently operated instrument for routine analysis of large amounts of data where precise linear measurements or resolution greater than about 100 lines per millimeter are not required. The viewing system of the "Class III" instrument was especially useful. An eight times (8x) enlargement of the entire sample is displayed at all times including during the scan. A smaller screen is used to provide a view of the sample through the analytical optics and is used for initial focusing and alignment.

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SIGNATURE: [redacted]

DATE:

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[redacted]

October 30, 1964
MJM:bjs-458

TRIP REPORT

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Subject: Trip to [redacted]

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Purpose: To evaluate [redacted] Microdensitometer and [redacted] Color Microdensitometer

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Reported by: [redacted]

Talked to:

Others Attending:

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On Monday, October 26, 1964 we visited the [redacted] to see the tri-color microdensitometer. they had just completed for [redacted] The instrument is basically the [redacted] Model 1032A* with the addition of two more photo-multiplier tubes, two more amplifiers and another two pen recorder. The light, after passing through the analyzing aperture, is separated into three non-overlapping spectral bands (specified by [redacted] by dichroic mirrors and filters. The outputs from each of the three channels (blue, green, red) are recorded on [redacted] recorders and can also be multiplexed onto magnetic tape. The instrument may also be used as a "black & white" microdensitometer.

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On Tuesday, October 27, 1964 we visited the [redacted] to test their microdensitometer. [redacted] a very small firm which started by producing microphotometers a few years ago, currently manufactures two models of microdensitometers. The newer model differs from their first instrument in that the light source is separately monitored to eliminate the effects of intensity fluctuations and to allow the photomultiplier tube to operate at a high average intensity level which lessens the effect of "dark current." A "dual beam" instrument of this type was not available at this time. Therefore, tests were conducted on the single beam version of the instrument. The standard logarithmic amplifier used with the [redacted] instrument to provide an output linear with density was also not available but they had "borrowed" a different log-arithmic amplifier to provide us with the density output. The "borrowed" amplifier's response time was much poorer than the standard amplifier's and this may have affected the edge trace data we obtained using the in-strument.

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* Described in Trip Report dated 17 July 1964, MJM:bb:335 jg

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October 30, 1964
MJM:bjs-458

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The [redacted] instrument resembles somewhat a scaled down version of the [redacted] instrument. The stage is close to the guiding ways and moves through about 2 inches along one axis. The lead screw is not directly attached to the stage. The lead screw drives a lever arm which in turn drives the stage. The accuracy of the stage travel has been tested interferometrically and found to be on the order of $\pm$ 1 micron under specified environmental conditions. Film samples can be firmly held down on the stage by a vacuum supplied to an annular ring which surrounds the glass area of the stage.

Both fixed scan speeds, or, as included on the instrument tested, continuously variable scan speeds are available. Selsyns are used with the continuously variable scan speed unit to synchronize the recorder drive and stage drive to provide a constant scale ratio (which can be altered by selecting various gear ratios) of stage motion to chart paper motion. The chart paper can be driven forwards or backwards to correspond to the direction in which the stage is moving if desired.

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[redacted] apochromatic objectives are used in the [redacted] instrument. The sample may be viewed directly by deflecting the beam to a focusing eyepiece using a mirror which may be flipped into the beam. A dichroic mirror can be permanently placed in position to allow for viewing while scanning, but at the expense of sensitivity.

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The [redacted] instruments range in price from $10,000 to $25,000 depending upon the model and the accessories ordered. The instrument was considered particularly convenient to operate and appears to be an excellent tool for photographic research where scans of 2 inches or less are required.

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Ext. 525

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[redacted]

October 27, 1964
JG:bjs-448

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To: [redacted]

From:

STATINTL

Subject: Safe Laser Powers for Microdensitometers

cc: [redacted]

References: 1. Manual of Physical Properties of [redacted] Aerial and Special STATINTL Sensitized Materials
[redacted] Jan. 1961 STATINTL

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2. [redacted] on the Theory of Bessel Functions, Cambridge, N. Y., 1962

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3. [redacted], Microdensitometer Sources and Detectors, [redacted] Memo No. JG:bjs-453

I. The purpose of this memo is to show that much more radiation than would be necessary for use in a microdensitometer can be applied to film without causing excessive heating. Excessive heating can cause warping of the base or distortion of the emulsion by means of stress formation within it.

Section II gives the assumptions necessary and justification for them. In Section III the temperature rise within the irradiated area is determined, and in Section IV the temperature rise in the surrounding area is found. In Section V a typical case is discussed.

II. Assumptions.

The film is assumed to be held between two ring-shaped pieces of metal, which provide an infinite heat sink. Later calculations will show that since most of the heat is lost from the surface of the film, the heat sink is not critical. Because one does not want Newton's rings, a sufficiently thick layer of air will be allowed to cling to the film, even if it is held between sheets of glass* or plastic, that it may be considered to be in air for purposes of heat loss.

It is further supposed that the film is heated uniformly over a small circular area in its center. Preliminary calculations show that the heat loss due to radiation is small compared to the surface losses.

*Oil immersion microdensitometers are not considered in this memo.

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Estar film bases undergo a change of phase at about 80°C No definite temperature is given for cellulose ester film bases, but about 100°C is typical. 100°C is also the point for steam formation within the emulsion. Because the emulsion will be heated more than the base, we may take the maximum temperature as 100°C. Assuming ambient temperature of 20°C, we have a temperature difference of 80°C available.

If the film emulsion has absorption properties uniform through its thickness, an exponential law of absorption will apply, with most of the heat being absorbed near the illuminated surface. To reduce the problem to two dimensions, the emulsion layer is replaced with a thinner one having uniform heat absorption, and a volume rate of heat absorption equal to or greater than the maximum rate of absorption of the real emulsion. This will cause the heat conduction rate to be underestimated, which is safe. For an emulsion with uniform properties, the thickness of the equivalent layer is the point at which all but $1/e$ of the radiation has been absorbed. This can be found by dividing the emulsion thickness by 2.3 times the diffuse density, the factor of 2.3 being the conversion from common to natural logarithms. For an emulsion developed to less than completion, the maximum density is less and will create less temperature rise.

Illumination has been assumed to be from the emulsion side. This system has the advantage that most of the heat is released near the air surface, and does not need to be conducted through the emulsion layer. This system also gives better definition when a small illuminating spot is used.

III Heated Region

The temperature rise in the heated region may be found by integrating the temperature gradients from the center to the edge. This temperature rise is to be added to the temperature rise in the surrounding region to obtain the total temperature rise.

Let:

r	=	distance from center of spot
k	=	thermal conductivity
L	=	equivalent thickness
t	=	temperature above ambient
P	=	power delivered to film
J	=	mechanical equivalent to heat
R	=	radius of heated area

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At equilibrium, the thermal gradient at any distance (r) from the center of the heated spot must be sufficient to conduct away the heat absorbed within the distance, r, of the center of the spot. The heat absorbed is

$$\frac{Pr^2}{JR^2}$$

and the cross section which it must be conducted through is

$$2\pi r L$$

with conductivity k, thus

$$-\frac{dt}{dr} = \frac{Pr}{2\pi R^2 J k L}$$

The negative sign applies because temperature decreases as distance increases.

The above equation may be integrated to give the temperature rise from the edge to the center of the heated area, or

$$t_{(0)} = t_{(R)} + \frac{P}{4\pi J k L}$$

IV. Cooled Region

Consider a ring with inner radius r and outer radius $r + \Delta r$. The heat conducted in is $2\pi r k L \left(\frac{-dt}{dr}\right)$ and that conducted out is $2\pi r k L \left(\frac{-dt}{dr}\right)\Big|_{r+\Delta r}$ where the symbols have the same meaning as in the previous section, and $\frac{dt}{dr}\Big|_{r+\Delta r}$ means $\frac{dt}{dr}$ evaluated at $r + \Delta r$. The heat lost by convection is $2\pi r (\Delta r) h t$ where h = convection coefficient. Setting heat lost equal to heat gained we have

$$-2\pi r k L \frac{dt}{dr} = 2\pi r (\Delta r) h t - 2\pi (r + \Delta r) k L \left(\frac{dt}{dr}\right)\Big|_{r+\Delta r}$$

Passing to the limit $\Delta r \to 0$, we obtain the differential equation

$$\frac{d^2t}{dr^2} + \frac{1}{r}\frac{dt}{dr} - \frac{ht}{kL} = 0$$

Letting $x = r\sqrt{\frac{h}{kL}}$

we have

$$\frac{d^2t}{dx^2} + \frac{1}{x}\frac{dt}{dx} - t = 0$$

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This equation has the solution $t = C_1 I_0(x) + C_2 K_0(x)$

where $I_0(x)$ and $K_0(x)$ are Bessel functions of order zero and pure imaginary argument ([redacted] p 77), and C_1 and C_2 are arbitrary constants to be evaluated by satisfying the boundary conditions. Two boundary conditions are: (1) the temperature gradient at the inside edge of the cooled area must be sufficient to conduct the heat away from the heated area, and (2) the temperature at the outside edge, where the film is clamped between metal blocks, is equal to ambient, or zero. In order for t to approach zero at large x, where

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$$|K_0(x)| << |I_0(x)| \quad , \quad |C_1| << |C_2|$$

Thus, for small values of x where $|K_0(x)| > |I_0(x)|$, $t \approx C_2 K_0(x)$ and since $|K_0'(x)| > |I_0'(x)|$, $t' \approx C_2 K_0'(x)$ i.e. if we are interested in small values (x) it does not matter how far away the heat sink is from the heated spot, as long as it is far away, and compared to the other dimensions of the problem, it is far away.

For small x

$$K_0(x) \approx -\ln \frac{x}{2} - \gamma$$

and

$$K_0' \approx \frac{-1}{x}$$

where $\gamma = \lim_{N \to \infty} \left[\sum_1^N n^{-1} - \ln N \right] \approx 0.5772$

Thus $$t = -C_2 \left(\ln \frac{x}{2} + \gamma \right)$$

and $$\frac{dt}{dr} = \frac{-C_2}{x} \frac{dx}{dr}$$

$$= \frac{-C_2}{r}$$

From the previous section, when $r = R$

$$\frac{dt}{dr} = \frac{-P}{2 \pi r J k L}$$

Thus, $$C_2 = \frac{P}{2 \pi J k L}$$

and $$t = \frac{-P}{2 \pi J k L} \left[\ln \frac{x}{2} + \gamma \right]$$

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or $$t = \frac{P}{2\pi JKL}\left(0.111 - \ln r\sqrt{\frac{h}{KL}}\right)$$

From the previous section $$t_0 = t_R + \frac{P}{4\pi JKL}$$

or $$t_0 = \frac{P\left(1.234 - \ln \frac{r^2 h}{KL}\right)}{4\pi JKL}$$

which can be solved to

$$P = \frac{4\pi t_0 JKL}{1.234 + \ln \frac{KL}{r^2 h}}$$

V. For example, take [redacted] plus X , thin reconnaissance base, [redacted] with a one micron spot. The appropriate values are

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to	=	80C°
J	=	4.185 joules/cal
K	=	5.38×10^{-4} cal/sec. cm °C
R	=	5×10^{-5} cm
h	=	1.3×10^{-4} cal/sec
L	=	6.82×10^{-5} cm (developed to a diffuse density of 4.85)

Then

$P = 1.2 \times 10^{-5}$
= 12 microwatts

This power is compared to that available from various light sources in Reference 3.

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October 30, 1964
JG:bjs-453

Memo for the Record

STATINTL To: [redacted]

From:

STATINTL

Subject: Microdensitometer Sources and Detectors

cc: [redacted]

References:

1. Reference Data for Radio Engineers. International Telephone & Telegraph Co. New York, 1956
2. R.C.A. Tube Handbook, Vol. VII
3. Spangenberg, K. R., Vacuum Tubes, McGraw-Hill New York, 1948
4. STATINTL [redacted] Safe Laser Powers for Microdensitometers. STATINTL [redacted] Memo No. JG:bjs-448
5. STATINTL [redacted], Intensity Stability of Laser Sources, STATINTL [redacted] Memo No. WCT:bb: 357

1. Introduction

The need to measure the density of photographic film with smaller effective apertures or greater scanning speeds than is currently possible can be satisfied by increasing the sensitivity of the detector, increasing the illumination on the sample, or both.

2. Detectors

The usual microdensitometer detectors are multiplier phototubes. These devices have sufficient gain in the multiplier section to insure that only a negligible amount of noise is introduced into the channel at later stages in the electronics. Power supply fluctuations, leakage, field-thermal and secondary emission, and shot noise are

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claimed to cause spurious response from these detectors (Ref.'s 1, 3).

2.1 Power supply fluctuations.

The gain of the multiplier section of a multiplier phototube is a function of supply voltage. A small percentage change in voltage causes a small change in the gain of each stage. However, when all of the individual stage gains are multiplied together to obtain the overall gain, a large change results. According to Ref. 1, p 410, a small change of P percent in supply voltage will cause a change of $n\alpha P$ percent in the output current, where n is the number of stages and $0.5 < \alpha < 0.7$. A change of $n\alpha P$ percent in current will be interpreted as a change of $n\alpha P$ percent in transmittance, or as a change of $\Delta D = \frac{n\alpha P}{100} \log e$ in density where $e = \lim_{N\to\infty} (1 + \frac{1}{N})^N$

If

$\Delta D \leq .01$

and $n = 9$, a common situation, then solving the above we have

$$P \leq 0.4 \text{ percent}$$

Computation from the current versus voltage curves of reference 2 for a 931A phototube at ~ 1000 V yielded essentially the same result. Power supply fluctuations cause spurious density readings regardless of signal level.

The above applies to systems in which the voltage is held constant and the phototube current is measured and indicates the need for closely regulated power supplies in such instruments.

The more common system, however, is the constant current system, in which the phototube voltage is varied by a feedback circuit in such a manner as to hold the phototube current constant, and the phototube voltage is measured and converted to density. This system is almost invulnerable to line voltage fluctuations, assuming well regulated reference voltages for the feedback circuit, because the large current change from a small voltage change of the phototube acts to increase the gain of the feedback circuit.

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2.2 Leakage resistance

Leakage between electrodes contributes to the dark current. But this resistance is in parallel with much lower resistances and should cause a slight shift in operating point, but no noise at all.

2.3 Field - Thermal and secondary emission.

At low signal levels, the primary noise source is the fluctuation in the dark current due to field-thermal and secondary emission, the secondary emission being caused by positive ions and electrons arising from bombardment of gasses in the vacuum tube. Although thermal emission by itself is negligible for most photosensitive surfaces it is aggravated by the strong electric fields within the tube, particularly if the cathode or dynodes have sharp corners or burrs.

2.4 Shot noise

The noise voltage depends upon the amount of smoothing done. For the usual case of a chart recorder, smoothing is certainly provided by the inertia and friction of the pen assembly if not elsewhere. If, however, a magnetic tape output with a high sampling rate is used, less smoothing can be done. In such a situation, the effective aperture of the system must be increased. Consequently, one could arrive at a situation in which the shot noise, which increases with effective aperture, other things held constant, became large compared to the noise due to field thermal and ionic emission. Letting (1)

$\overline{i_1^2} = S^2 N^2 B^2$ = mean square noise current due to field thermal and secondary emission

$\overline{i_2^2} = 2 e S B L$ = mean square noise current due to shot noise.

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S = sensitivity

N = noise equivalent input

B = bandwidth

e = charge on the electron and

L = luminous input,

the inequality $I_2^2 < i_1^2$ will be satisfied if

$$B < \left(\frac{2 e \rho}{S N}\right)^2$$

where ρ = current signal to noise ratio.

For a median 931A phototube, we have
$S = 30 \times 10^{-6}$ amp/lumen and
$N = 9.5 \times 10^{-13}$ lumen sec$^{\frac{1}{2}}$.

Also, $e = 1.6 \text{ c } 10^{-19}$ amp sec, and for an equivalent density error of .01 $\rho = 43$. Thus, for $B < 4$ cycles/sec, the case for strip recorders, phototube dark current noise predominates, but,for tape recording.shot noise predominates.

2.5 Refrigeration

Refrigeration decreases the noise of the phototube under most conditions. According to reference 2, refrigeration of a 931A phototube to -75° C (approximately the sublimation point of dry ice) increases its detectivity (reduces the noise equivalent input) by a factor of 20. But, film should be assesed in an environment with proper relative humidity. For 20°C and 50% relative humidity, a window approximately 3 1/8" thick would be required to prevent condensation of moisture. Thus, special optics would be required to pre-correct for the effects of the refrigeration apparatus.

2.6 Remarks on Multiplier Phototubes

The characteristics of multiplier phototubes of the same type and make vary widely. Selection is common practice. Therefore, not much validity can be attached to the procedure of measurement of the sensitivity of one instrument of a make and type and taking this to be the

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sensitivity of all instruments of that make and type. Finally, the tubes do fail, and after the first tube fails, the sensitivity of an instrument will depend on the detectivity of the next phototube selected.

3. Sources

Mercury arc and laser light sources can increase the illumination of the sample, but create special problems of their own.

Comparison of mercury arc and tungsten light sources is straight forward and universal. It is done on the basis of brightness alone. Tungsten at 3360°K, taken as a standard, has a brightness of about 3,095 candles/cm^2. The brightest mercury arcs have a brightness of 140,000 candles/cm^2. Also, for a device with S-4 response (such as the 931A phototube) the efficiency of mercury light is 2.23 times that of tungsten light. Thus, the mercury light gives about 100 times as much effective illumination as the tungsten.

The comparison for laser light is not as straight forward, because the laser illumination depends on the size of the illuminated area, whereas (for reasonable sample sizes) the thermal source illumination does not. For a circular spot with the smallest N.A. permitted by the diffraction limit the tungsten gives 7.4 microlumens, and for an 80:1 rectangle, 750 microlumens. A 12 microwatt laser [(4)] will give 1.9 millilumens. The phototube sensitivity to the laser light is less than to tungsten, and the 1.9 millilumens, are equivalent to 420 microlumens of tungsten light.

3.1 Stability

The major problem with the mercury arc source is the lack of stability, which will require compensation. An investigation of the stability of laser sources may be found in Reference (5).

4. Conclusion & Recommendation

It is concluded that for small effective apertures either mercury or laser sources will provide an increase in instrument sensitivity. If the two orders of magnitude available from mercury are sufficient,

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either a mercury or a laser source may be used. The 12 microwatts of reference 4 are safe for steady state. At the risk of damaging the film should the scanning stop, one could use much more laser power, so that if the 2 orders of magnitude of the mercury are insufficient, laser power is recommended.

For larger effective apertures the mercury is the most effective source, the croossover point being at about 1000 square microns for a numerical aperture of 0.4 and at larger areas for smaller numerical apertures.

It is further recommended that source possibilities be exhaused before attempts are made to increase the detectivity of the detector because of the selection problems associated with phototubes and the optical and supply problems of refrigeration.

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October 28, 1964
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STATINTL

To: [redacted]

From:

Subject: Some considerations in the design of an improved microdensitometer system

cc: [redacted] STATINTL

As a result of the survey of microdensitometers conducted for project Microcap much information was obtained on a variety of microdensitometer systems. While several of the instruments surveyed do reflect the current state-of-the-art of microdensitometer design it is felt that an instrument of improved performance could be produced at this time by incorporating the best features of each of these instruments into a single system.

A brief discussion of the features of each instrument which are considered the best follows.

The basic components of a microdensitometer are the mechanical system (stage drive, guiding ways, lead screws), the optical system and the electronic system.

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The best mechanical system appears to be that developed by the [redacted] Their long experience in the production of precision comparators has enabled them to develop a microdensitometer stage drive system with micron, and possibly sub-micron accuracy over approximately 10 inches of stage travel in either the x or y direction. Many present and future uses of microdensitometers (such as the present moon map project of ACIC) will require micron or sub-micron accuracy for linear measurements.

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The optical system employed by [redacted] including the viewing system used on their "Class I" instrument, appears to be superior to other optical systems based on the modulation transfer functions obtained from the edge traces and sine wave test pattern traces. Further improvement over the [redacted] optics should be possible by using an illuminating objective with a numerical aperture approximately 0.8 that of the analytical objective as was determined, theoretically, by [redacted]* The viewing system should be modified somewhat to provide for, when desired, direct viewing

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*[redacted] memo by [redacted] (RK:bb:406) 31 August 1964
and [redacted] memo by [redacted] (RK:bb:283) 22 June 1964, Revised 9 July 1964

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of the sample image, instead of displaying it on a ground glass screen. The granular structure of such a screen obscures small detail making focusing of such detail difficult. The use of a [redacted] lens to distribute the light over the photomultiplier surface (used by [redacted] on their "Class I" instrument and on the [redacted] instruments) is also considered necessary for the optimum performance of the instrument. Both bilaterally adjustable and fixed scanning and illuminating apertures should be incorporated in the system.

The amplifiers and associated electronic circuitry, including a [redacted] recorder and the [redacted] end window photomultiplier such as that used by the [redacted] in their [redacted] Microanalyzer provide the most versatile (logarithmic or linear amplification), sensitive (approximately 0-4 in density with less than 1μ^2 area) and stable electronic system for a microdensitometer. The [redacted] electrical system for the illuminating lamp incorporates such desired features as adequate isolation and heavy soldered connections throughout the circuit to prevent intensity fluctuations due to line voltage changes. This type of system should be used in any future microdensitometers. To reduce the effects of lamp intensity fluctuations further a form of the double beam system (utilized by [redacted] in which lamp intensity fluctuations are detected by a separate photomultiplier system, could be used to compensate the output of the main amplifier. For high speed data aquisition a digital recording system must be employed and it is suggested that a system such as that produced by the [redacted] be adopted. This system uses magnetic tape, allows for programming scan patterns, adding alphanumeric data, provides for density clipping, and can record data at a rate of 3000 cycles per second.

Various auxiliary features could be added to increase the versatility and/or performance of the microdensitometer. A gas bearing platen such as that developed by the [redacted] provides an excellent means of keeping the sample firmly against the supporting medium and its use is strongly suggested. In the event that focus is changing because of emulsion characteristics (it should not change due to nonplanar stage motions in a well designed system), a device similar to [redacted] automatic focusing device could be used. A more sophisticated design would be necessary, however, since the [redacted] device seriously decreases instrument sensitivity and response time. The use of a special recording unit, a raster scanning system, and a density level coder would enable the instrument to plot isodensity contours. Such a system has been developed by the [redacted] for use with the [redacted] instrument which is especially suited for such an application. An isodensity system could, however, be adapted to any microdensitometer without undue difficulty.

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The various features described above could be incorporated into a single instrument since there is no problem regarding the compatability of the separate components discussed. Based on the cost information obtained from the various microdensitometer manufacturers, it is estimated that a system incorporating all of the above features would entail a development cost of approximately [redacted]

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