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A Study of the Effects on Sigma D and Resolved Lines as a Function of Spatial Multi-Superposition of Images

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A STUDY OF
THE EFFECTS ON SIGMA D AND RESOLVED LINES
AS A FUNCTION OF SPATIAL MULTI-SUPERPOSITION OF IMAGES

by

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ABSTRACT

In photography the fidelity of the image is often degraded due to the random graininess associated with photographic emulsions

A study was performed to obtain objective and subjective data on the effects of granularity and graininess as a function of the number of spatially superpositioned images.

A target was designed and built.* Individual negatives were made utilizing copy equipment with a vacuum back to ensure precise registration during exposure. These individual negatives were then imaged onto 16mm film utilizing standard motion picture equipment and a vacuum platen which was designed and built to ensure precise registration of individual negatives during the motion picture exposure.

This study showed a significant enhancement of images brought about by a technique which might be made practical on a routine basis.

BACKGROUND

Since 1926 with the initial work of Hickman[1], methods of image enhancement and reduction of noise by increasing signal-to-noise ratio have been investigated. In 1963 Kohler & Howell[2] performed a study on the effects of optically superpositioning three images. Their investigation showed significant gains in Resolving Power and reduction of Sigma D, but they concluded that the technique was not practical on a routine basis.

In 1960 Jerome Katz, one of the authors of this paper, conceived and discussed possibilities of recording multiple images in

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1 K.C.D. Hickman, Journal of the S.M.P.T.E., #25: 49 (1926).

2 Kohler & Howell, Photographic Science and Engineering, Vol. 7, #4, January 1963, p. 241.

* See Illustration opposite p. 3.

space vehicles* or high flying aircraft by employing banks of T.V. cameras and telemetering the electronically correlated images to the ground for tape storage and subsequent viewing on a screen with gains in definition.

This paper discusses a method of image enhancement utilizing the position of a series of similar negatives with the same informational content. This study had a dual purpose: first, to study the effect of superpositioning on the chosen parameter, and second, to determine if this method is feasible for routine application.

The response variables chosen were resolving power and granularity, analyzed as functions of the number of superpositions, density level, and operators performing the measurement. Granularity was measured as the standard deviation of independent density values about a mean for a large number of samples. Assuming a random distribution of the grains, the probability that the local spatial density fluctuations for similar negatives will be the same approaches zero.

The non-random nature of image as opposed to the random nature of the grain structure of the emulsion is the fundamental basis for the improvement of the signal-to-noise ratio obtained from this method.

EXPERIMENTAL OBJECTIVES

1. To investigate how resolved lines and Sigma D are related at fixed density values as the number of spatially superpositioned images increases.

2. To evaluate this experimental technique of image enhancement by superposition of images and establish if it can be made practical on a routine basis.

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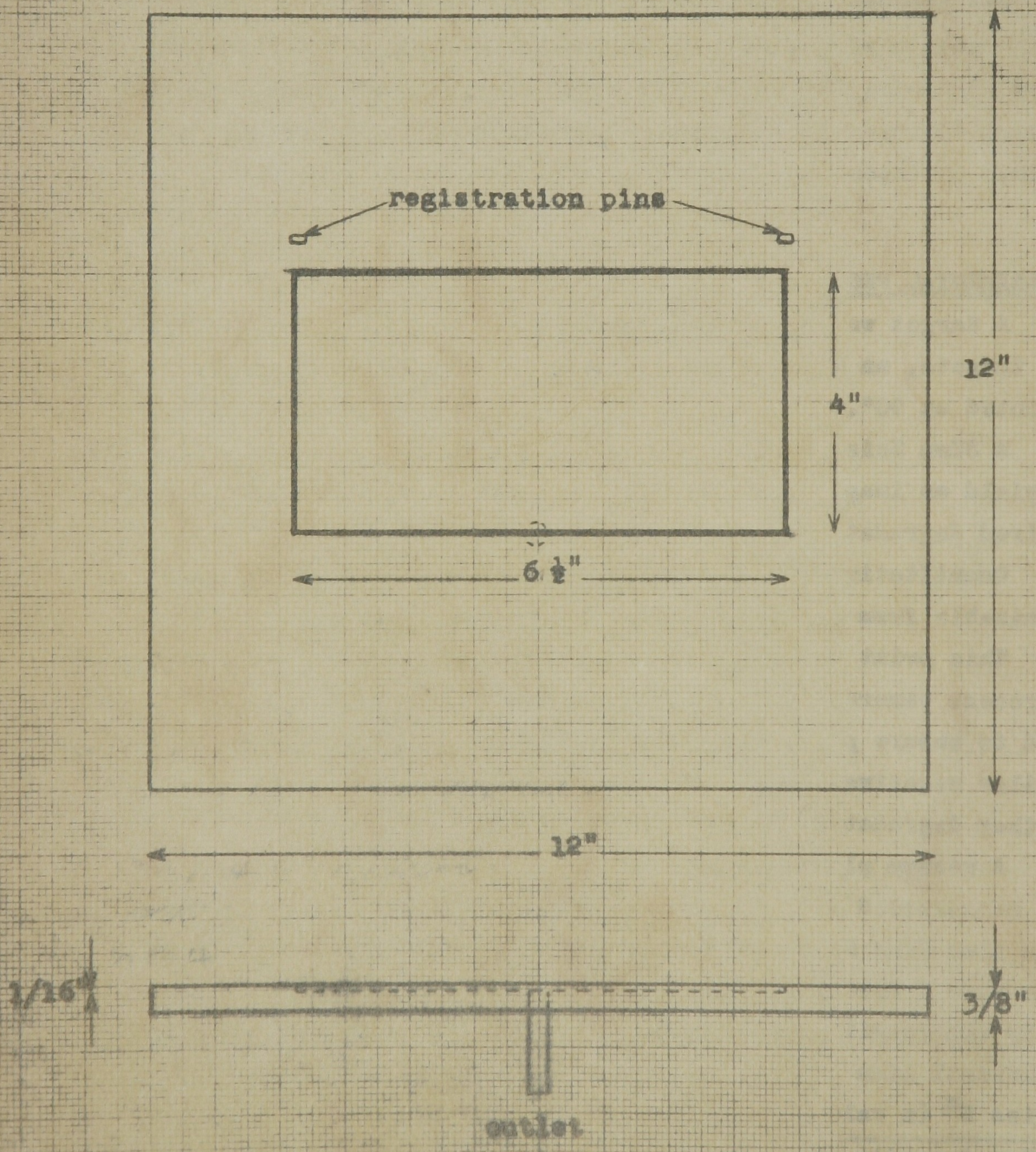
* See Illustration opposite p. 1.

VACUUM PLATEN

scale: 1 cm. = 1 in.



SCOPE OF THE EXPERIMENTAL STUDY

Special equipment was designed and built and an experimental study carried out to determine the effect on resolved lines and Sigma D at 4 density levels when as many as four identical negatives were spatially superpositioned.

The program included the production of sixteen similar negatives that were within a tolerance variability of ± .02 density units at d-min. Production of single negative and multi-spatially superpositioned images was made with objective and subjective evaluations of these images being performed.

EXPERIMENTAL PROCEDURE

A target was designed incorporating two high contrast resolution targets, an area of uniform density, and two knife edges oriented at 90°. (Adox Resolution Target used in this experiment.)

A 35mm Zeiss Contaflex camera was used to copy this target and to yield an image that when magnified 60X and printed produced the desired degradations.

Quantitatively this was 60% of the maximum resolving power obtainable from the targets representing 90 lines/mm.

This print was then copied at a magnification of 1:1, utilizing a process camera. Pin registration and vacuum back equipment were used to ensure precision in registration during individual exposures Similar negatives were produced on fine grain film to minimize any further degradation of the copy original.

A vacuum platen incorporating pin registration was designed and constructed to register similar negatives for final exposure. By a 16mm Cine Special, the individual negatives were photographed onto Plus X Reversal film. The exposures* were altered by spatially superpositioning a number of these identical negatives on individual 16mm frames. The first three terms of the arithmetic series 2^n (n values of 0,1,2,...N) were investigated. This study

* See Appendix C.

was performed at 4 density levels.

A large neon lamp source illuminated the negatives during integrated exposures. A calibrated step wedge was positioned so as to be recorded on all 16mm frames.

The exposure area comprised only 1.85% of the entire emitting surface area, to ensure evenness of illumination.

The 16mm motion picture film was processed at a local television station. A sensitometric control chart was established and maintained during the processing period. Control parameters utilized were d-max and contrast.

Microdensitometry* was utilized to scan the samples for granularity. The experiment was twice replicated, requiring 24 traces to be made. Approximately 800 points per trace was used for the determination of Sigma D yielding an accuracy of ± 15% at 2σ . The computer was used for the calculations of Sigma D.

Resolved lines/mm was accomplished by utilizing a Baush & Lomb microscope at 60X magnification.

Two observers having independent intensity modulation control by use of a Variac determined the resolved lines of the samples[3]. Samples were placed in glacine envelopes and numbered from 1-24. Measurements were made and recorded adjacent to the appropriate number. After the samples were evaluated, they were then correlated corresponding to exposure, integration, and density level information. These precautions were initiated to offset bias of the observers.

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* Density levels 1, 2, 3, 4, have step wedge D minimum of 1.0, 1.25, 1.50, 1.75. All steps are ± .10 density units for replicates and within a density group for all integrations.

3 P.D. Carman, W.N. Charman, <u>Detection, Recognition & Resolution in Photographic Systems</u>, Division of Applied Physics, National Research Council, Ottawa, Canada, December 1963, Vol. 54, #9, Journal of the Optical Society of America.

DISCUSSION OF RESULTS

RESOLVED LINES/mm. Density levels showed no statistically significant effect on the resolved lines/mm.

Further investigation of mean density levels showed that as integrations increased, the number of significant different density levels was reduced from three at one integration (where D_3 was not different from D_4) to two levels at four integrations (where only D_3 was significantly different compared to levels 1, 2 & 4). (Graph 1.) The error was 38% of that of the density factor. Interaction between the factors investigated was not significant. Considering the multiplicity of variables including three separate stages of registration coupled with normal process variability, this relatively large error term was below the expectation of error for the experiment.

An increase in resolving power due to spatial superposition of images was found to be highly significant. Investigation of integrated means (when density was held constant) showed no significante between the single and the two superposigioned images at the first three D levels. The image composed of four spatial superpositions was significantly different from both the single and 2 integrations at the two high density levels.

The first and second density levels did not indicate a significant increase in resolved lines as a function of multi-superposition of images. This was attributed primarily to the low density levels where an optimum of resolved lines per mm was noted for the single image exposures. (Graph 1.)

As the number of superpositioned images increased, the rate of change of resolving power as a function of four superpositioned images reached a maximum at the third density level. (Graph 2.)

Resolved lines for the single exposure as a function of density level steadily decreased, reaching a minimum at the 4th density level, accounting for a total loss of 11.2% between the first and fourth density levels. (Graph 1.)

The highest gain in resolving power as a function of superpositioning of images was noted at the third density level, where the increase totaled about 20%. (67 lines to 83 lines.) (Graph 1.)

ENVIRONMENTAL STABILITY. A measure of environmental stability during the final registration and exposure was accomplished by utilizing as the response variable the linear distance on the microdensitometered trace representing the knife edges on the samples*; neither the vertical nor horizontal factor was significant.

The error associated with both these factors was 50%.

Investigation of the means between integrations gave a measure of how the linear distance across the traced edge varied as a function of superposition of images. The vertical edge showed a maximum variability of 2.2% between the single and the 4 intergration samples. Horizontally, the maximum mean variability was 5.3%.

The higher variability was probably due to more side motion during the rewinding stage of exposure.

SIGMA D. Both density levels and superposition of images had a significant effect on Sigma D. Investigation of means for Sigma D at each density level relative to changes in integration yielded the following results.

At density 1, the single exposure and the two superpositioned images were not significantly different. Both were significantly different when compared with four superpositioned images. (Graph 3.)

At density levels 2 & 3, both the two and the four superpositioned images were significantly different from the standard single exposure.

At density level 4, the image consisting of two superpositioned standards was not significant. Although the four time integrated image was significant, the trend indicated in Graph 3, if extrapolated, shows these curves approaching non-significance.

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* See Illustration p. 10.

There was 6.8% error associated with this analysis of variance relative to the factors investigated.

Test of means of Sigma D when integrations were held constant indicated that density levels 1 and 2 or 3 and 4 were estimates of the same mean value for the single standard non-superpositioned image. At 2 integrations, the density levels were all significantly different, but at 4 superpositions, the 3rd and 4th density level values were estimates of the same mean value. (Graph 4.)

The reduction in Sigma D for this experiment was as follows. At density level 1, the change with integration was not statistically significant. (Less than .01 Sigma D units.) The reduction at density level 2 was 34.5% At density level 3 the decrease was 32.3% where the rate of change of Sigma D was still increasing rapisly at 4 integrations. At density level 4 the reduction was 15%. (Graph 4.)

CONCLUSION

1. There is a definite increase in resolved lines/mm coupled with a decrease in Sigma D as a function of multi-superposition of similar images.

2. The study showed that there was no significant difference in either resolved lines or Sigma D due to 2 superpositions relative to the standard. However, there was a significant improvement in resolved lines and reduction in Sigma D between 2 and 4 integrations. This would suggest that further investigations proceed directly from 1 to 4 to some higher number of superpositions.

3. With precise registration techniques as demonstrated by this experiment, image enhancement by techniques of multi-superposition is possible.

4. Further experimentation is required before practicality on a routine basis can be demonstrated.

5. It appears that an optimum mean density value for maximum effect from this procedure occurs at a density of 1.5. It is suggested that further investigations use this as a starting point.

APPENDIX A

The environmental stability measurements indicate that there was little error introduced in the registration phases.*

APPENDIX B

To minimize operator variability while making resolving power measurements, a Variac was used allowing each operator to control light intensity while viewing. Statistical methods applied to resolved lines/mm showed no significant difference between operators at the 5% critical probability.

A secondary experiment was performed using 2 operators and two fixed light intensities determined by voltage. Two voltages of 110 and 50 volts were investigated. Twenty-four samples were viewed by each observer with replication.

In all 96 samples, resolved lines/mm was greater at the lower voltage. The average increase for all samples was 10% with several increases measured to 17%. This gain may be attributed to the change in spectral energy distribution of the lamp toward red at the lower voltages. This spectral shift toward longer wavelengths probably accounts for less scatter and for more gain in resolved lines/mm.

APPENDIX C

ADDITIVITY OF EXPOSURE. Equal division of exposures was utilized during this study. Results have shown that the additivity of exposures is not sufficiently accurate in this application. What is required is a characteristic curve of the camera material so that exposure may be determined in terms of what is required to produce equal density increments.

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* Each measurement was a mean of 4 samples.

APPENDIX D

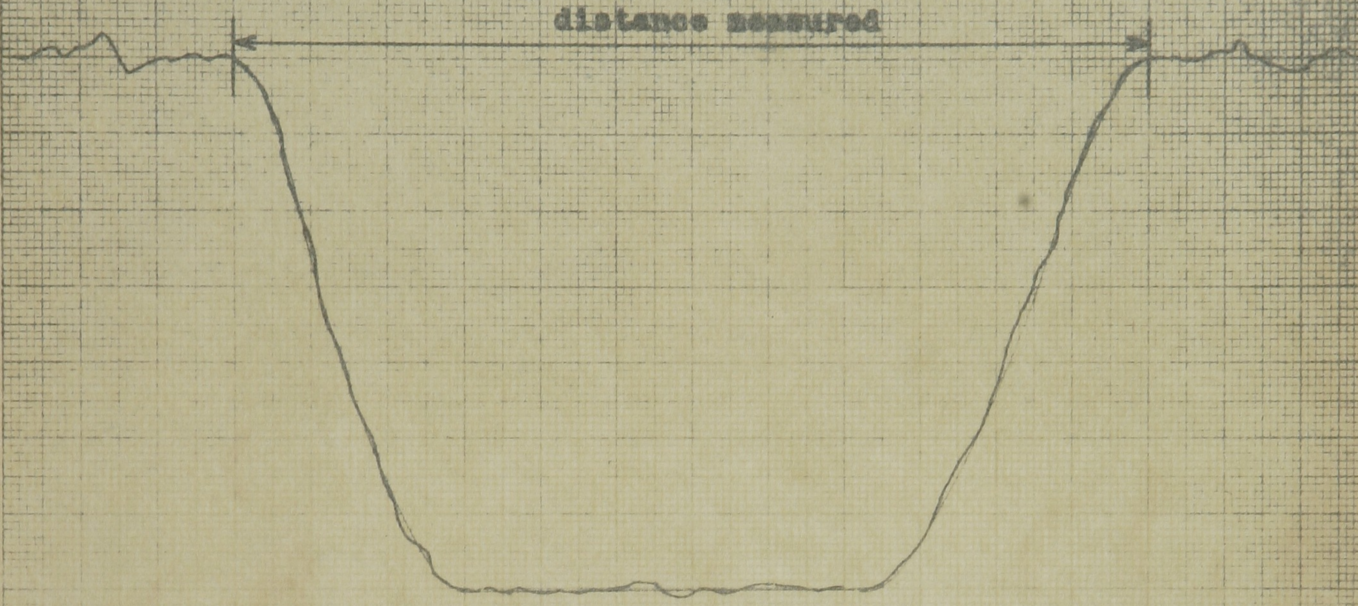
STATISTICAL CONSIDERATIONS. Statistical methods applied to this experiment consisted of analysis of variance and least significant difference of means. A critical probability of .10 was accepted for all tests. Where significance was found other critical probabilities were investigated. (Highly significant refers to a critical probability of .005.)

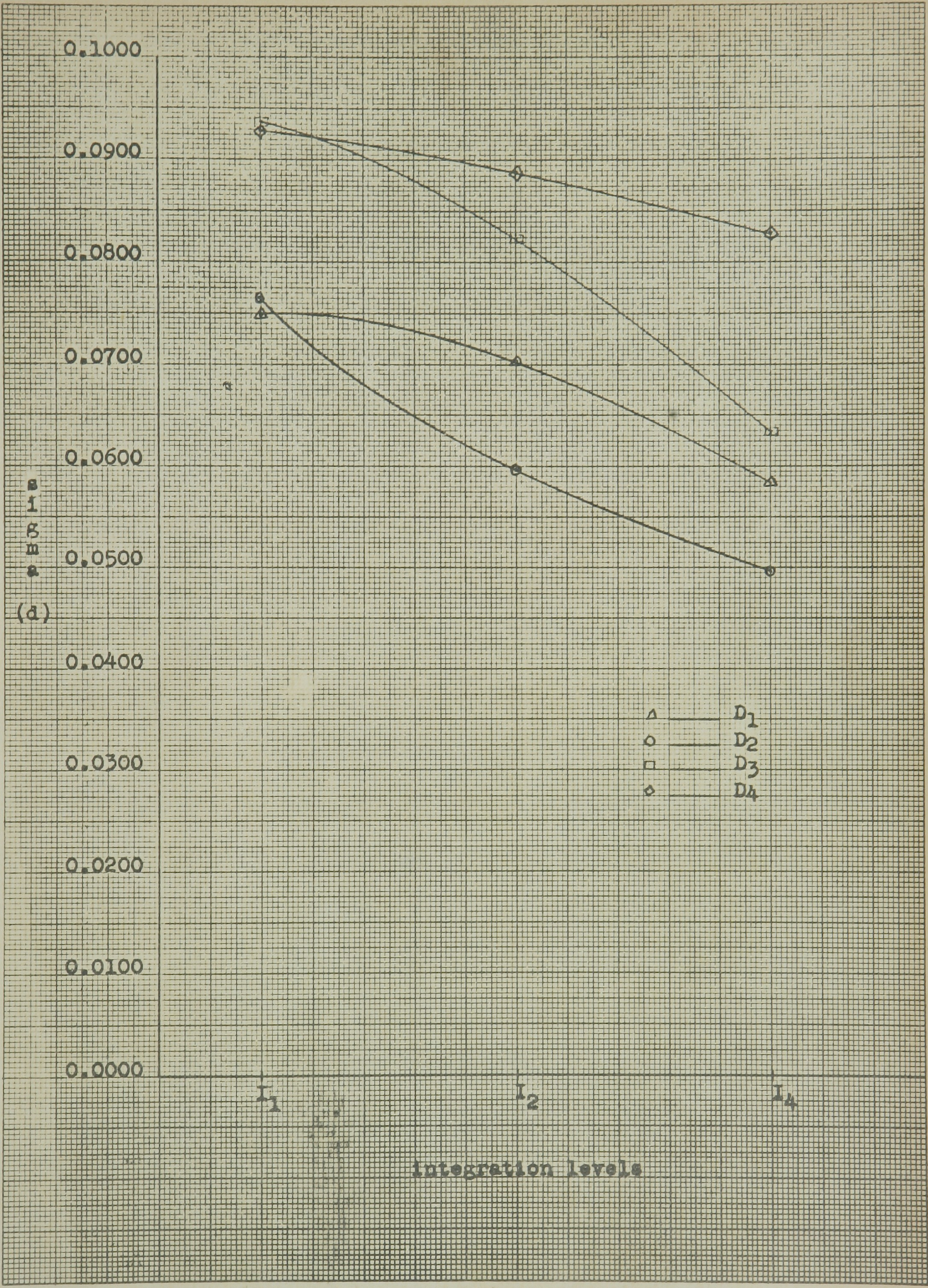
Graphical representations were correlated with statistical results and agreement was found in all cases. This correlation was obtained by utilizing the techniques of least significant difference of means.

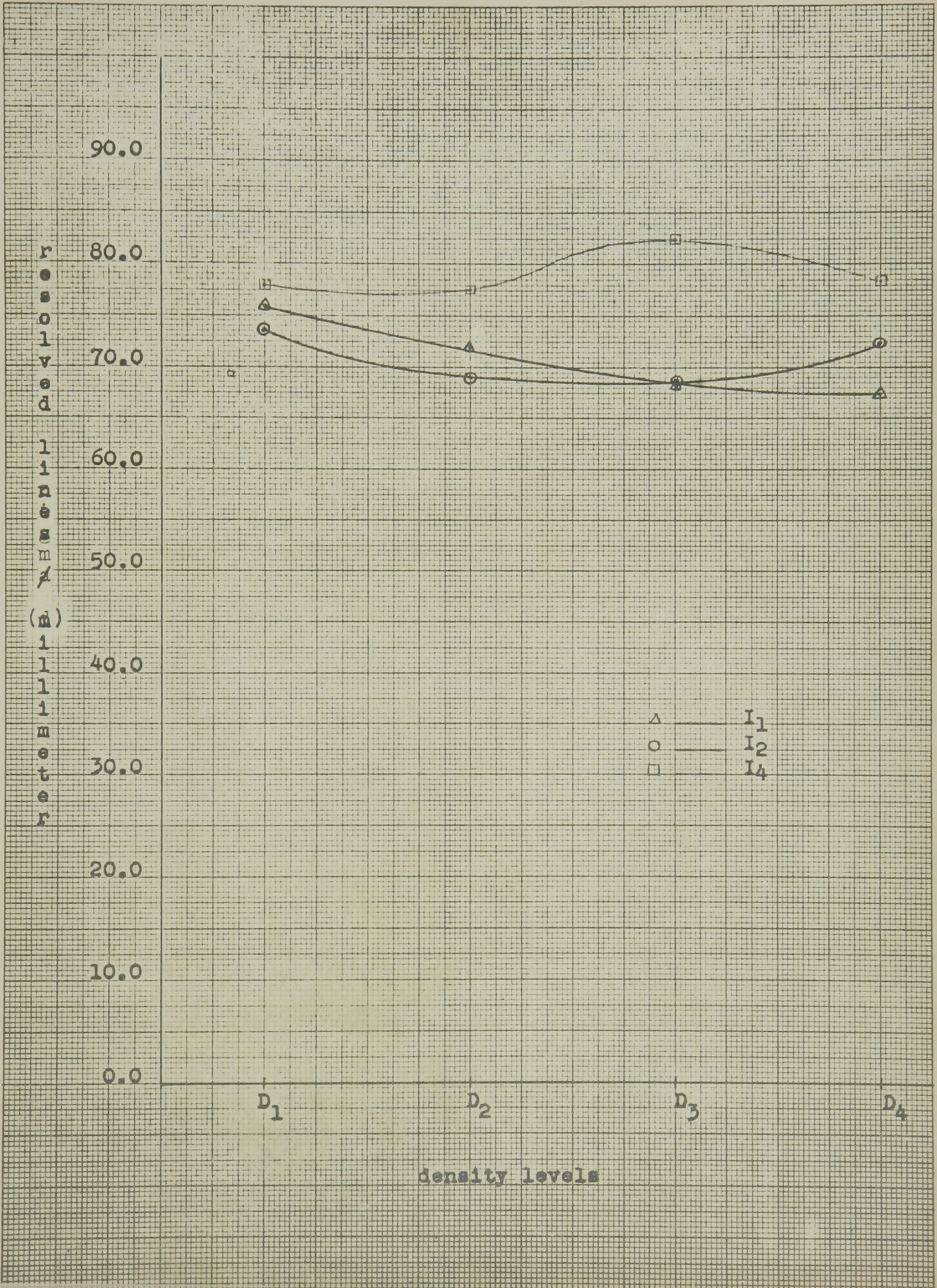
APPENDIX E

Further experimentation should be conducted to establish the limitations of this process. Such a study might include a resolution target of continuous frequency progressing to several hundreds of lines/mm.

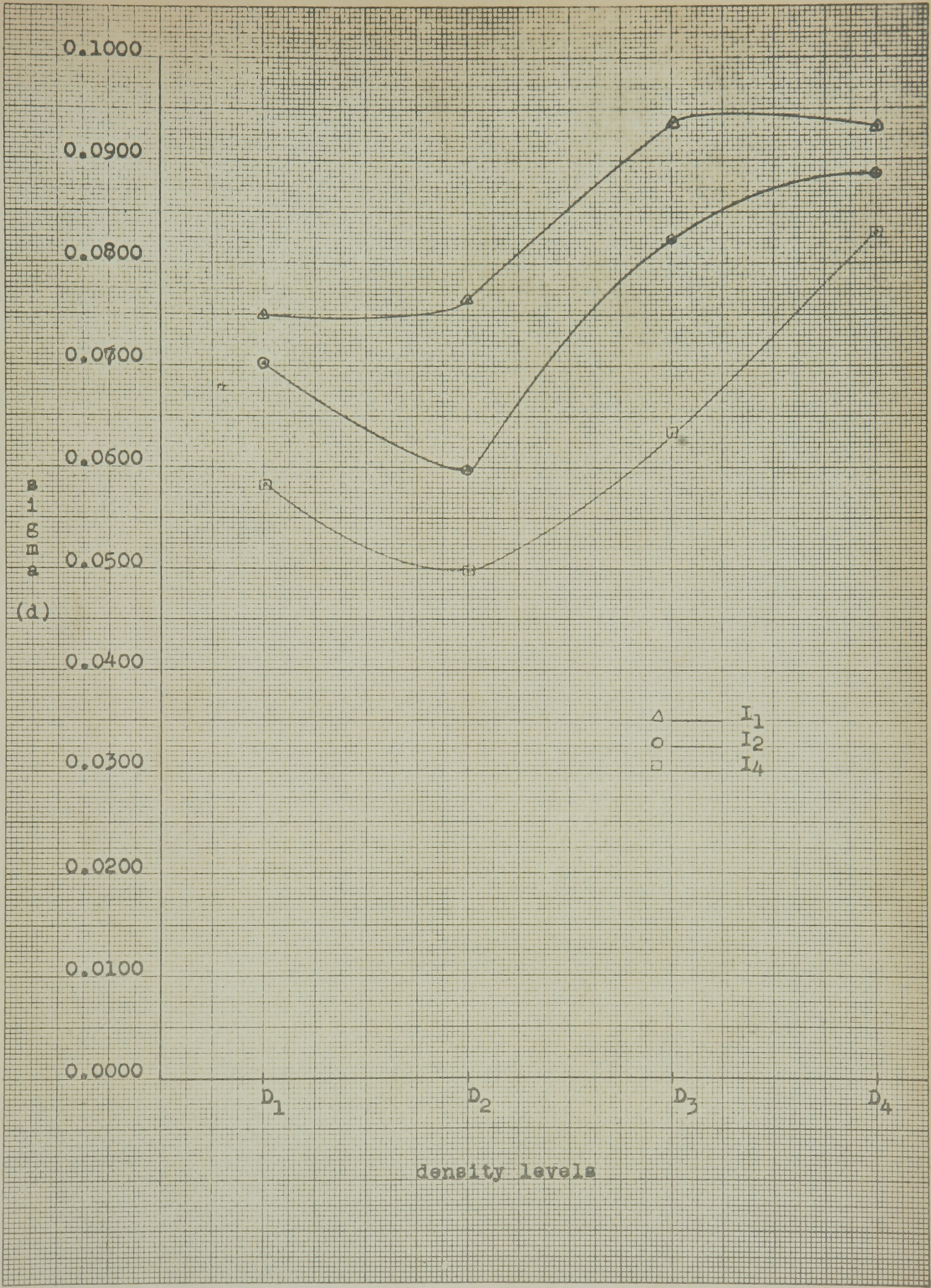
SAMPLE EDGE TRACE FOR ENVIRONMENTAL STABILITY



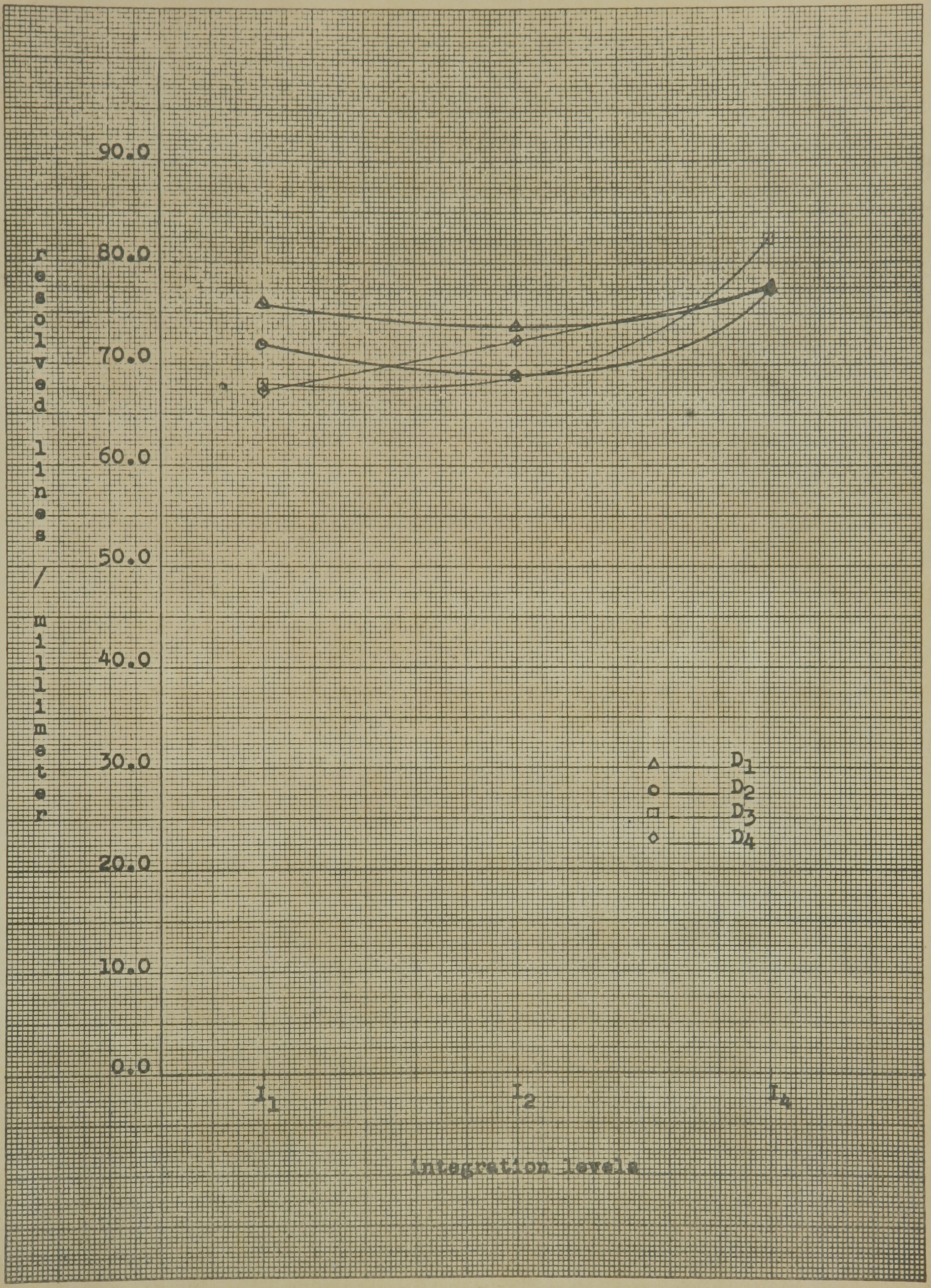

0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
s i g m a
(d)
D1
D2
D3
D4
I1
I2
I4
Integration levels



resolved lines/m (millimeter)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
D_1
D_2
D_3
D_4
density levels
△ I_1
○ I_2
□ I_4



0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
sigma
(d)
D_1
D_2
D_3
D_4
density levels
I_1
I_2
I_4


resolved lines / millimeter
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
I1
I2
I4
integration levels
D1
D2
D3
D4
FREDERICK POST COMPANY
SOLTON MILLIMETER 10X10 PER CM

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