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An investigation of flexographic duotone reproduction with variations in press pressure settings

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MASTER'S THESIS

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An Investigation of Flexographic Duotone Reproduction with Variations in Press Pressure Settings

by

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December 19, 1986

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ABSTRACT

Improved print quality has been become an important issue for the flexographic printing method. This is especially true in the area of fine quality halftone reproduction. The nature of this printing method which uses elastic materials for its printing plate is difficult to control. The main issue is the control of the pressure between the plate and the substrate. Extensive research has been done to change the hardness and the structure of the plate, however, the pressure used to transfer ink still remains a critical factor in achieving good halftone quality. Although the critical pressure control of the impression from plate to substrate is accomplished mechnically by the press operator, the pressure between the plate and substrate appears to be physically uncontrolable. Equal pressure across the plate to the substrate can create a large quantity of dot gzin in the highlight area. This problem is caused by the relief height difference between the highlight and shadow areas.

This paper suggests a solution to the problem of excessive dot gain in the highlight areas by the use of the duotone technique. A test was performed which compared a normal duotone technique using equal plate pressure for each plate and a experimental duotone technique for flexography

which involves the use of a different amount of pressure for each printing plate. The tonal rendering characteristics were determined and compared for each duotone technique. The test results indicate that there was no improved image quality by the use of the experimental duotone technique described in this paper. Suggestions are included for further study on this subject to improve halftone quality by flexography.

CHAPTER I

Introduction

Flexography is a high-speed method of relief printing, in which a highly fluid ink is transferred by a flexible plate to a moving web through rotary action.[1] A basic flexographic ink transfer system depends on the four rollers which are Fountain, Anilox, Plate, and Impression rollers. The amount of ink is controlled by a wiping action between Fountain and Anilox rollers. A reverse doctor blade can be used for more efficient ink control with increasing press speed (figure 1). Flexographic inks dry before the next printing station because they are a fluid-type ink with a greater evaporation rate than a paste-type ink.

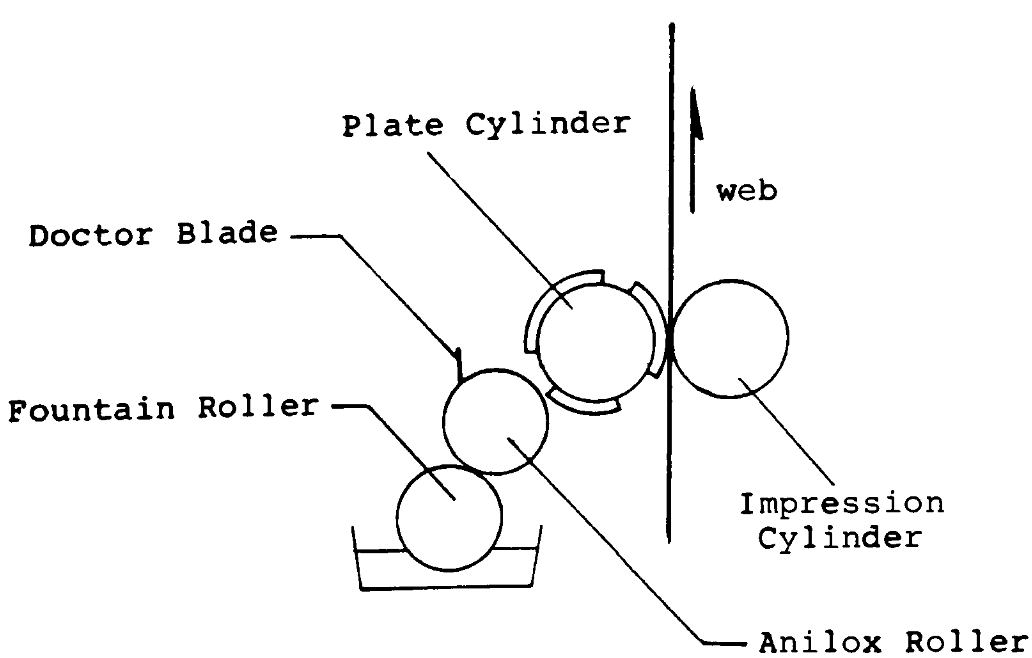

Figure 1. Schematic of a Flexographic Press

Historically, flexography has been known as an inexpensive, lower quality printing technique, used mainly for less expensive packaging printing. However, with advances in flexographic plate and press technology, the print quality has been improved considerably. The reason flexography has become more commonly used is its capability of meeting the needs of newer packaging materials.[2] Common applications of flexography are not only printing on porous materials, such as corrugated boards, milk cartons, and newspapers, but also for non-porous materials, such as plastic films and foils.

These are the advantages of flexography:

1. The ability to print on a wide variety of substrates;
2. Inexpensive plate costs;
3. A variety of cylinder repeat lengths;
4. The use of fast drying ink;
5. The ability to make small changes without changing an entire plate; and
6. The ease of removing a plate cylinder from a press.

However, a major disadvantage is its inability to reproduce a fine screen rulings.

There are two types of plates used in flexography. One is the Molded Rubber Plate, using natural or synthetic rubber. This plate-making system requires a more

time-consuming process than the Photopolymer Plate System. (Appendix A-1 for the rubber-plate making process)

The other method, the Photopolymer Plate System, is a relatively simple plate-making process. The photopolymer plate can either be a liquid or a pre-sheeted plate. Pre-sheeted photopolymer plates are commonly used because of the consistency in plate thickness. A negative film is required for the process which must have a matte surface. Because of the thickness of a flexographic plate, a long exposure time is required for sufficient polymerization. Therefore, a matte emulsion film which has many minute air escape channels is required on the emulsion side of this film to ensure good contact between the film negative and the photopolymer plate in the vacuum frame.[3] (Appendix A-2 for the photopolymer plate making process)

The molded rubber plate and the photopolymer plate can be compared from many points of view.

The Molded Rubber Plate has the following advantages:

1. Lower material cost.
2. Long period of plate storage capacity.
3. Stability on the cylinder during a press run.

The Photopolymer Plate has the following advantages:

1. Higher maximum resolution capacity.
2. No plate shrinkage or stretch problem.
3. Consistency of the plate thickness.
4. Simple plate making procedures.

Although the photopolymer plate has the advantages of finer screen reproduction capability and more simplified plate making procedures, the molded rubber plates are still more commmonly used in the wide web flexographic industry because of the lower cost of the rubber material. Photopolymer plates are used for label printing and newspaper production because of the requirement for a finer quality halftone reproduction. Another reason is the speed and simplicity of the photopolymer plate systems.

Although many improvements have been made in both molded rubber and photopolymer plates, there are still problems that exsist which cause decreased print resolution. One problem is the required pressure between the printing plate and the substrate; plates always have to be under a certain amount of pressure to accomplish the ink transfer. This squeeze pressure causes a dot distortion and enlargement which leads to "dot gain". This is especially a problem in the highlight areas because the elastic plate material that is used for the flexographic plates is unstable in highlight areas. Another problem is the inconsistency of plate thickness, which caused by elongation of plates, "cupping," and the mechanical tolerance in the plate making process. Therefore, more pressure is required between the plate and the impression cylinder to transfer ink properly. The excess pressure also leads to "dot gain."

(References can be found in the literature review section of this paper.)

In the shadow area, because of the use of fluid inks which have higher surface tension than that of paste-type inks, "fill-in" is easily caused. As a result, the reproduction density range in flexography is shorter than that of the other printing methods. This leads to a limited reproduction capability when attempting to reproduce photographic originals. Excessive dot gain in the highlight areas caused by the pressure between the plate and the impression cylinder is one of the major factors in the limitation of print resolusion. This research paper will attempt to investigate these problems.

In production, although a minimum impression must be maintained for the ink transfer, if less pressure is applied to minimize highlight dot gain, the pressure in the shadow area is too light to transfer ink properly. Extra pressure is required for an adequate ink transfer in the shadow area, however, this excess pressure causes a large amount of dot gain in the highlight area. The inconsistency of the plate thickness is another problem resulting in decreased fine detail reproduction capability. As a result of these problems, the density of the highlight areas are darker and the density range of the reproduction is shorter than those reproduced by other printing processes. These problems may be solved in flexography by the use of a special technique.

There is a printing technique called "Duotone Printing" that extends the density range by using two image carriers of the same image. This technique can produce images closer to that of the original photograph.[4] A good black-and-white photograph with glossy paper has a density range of 1.8 or higher. However, a single impression of black ink normally produces a density of about 1.4 on a press sheet.[5] Because of lack of the density range in using one layer of ink, there is loss of contrast somewhere in the tonal range. A second-impression is necessary in shadow areas to obtain the same density range as the original.[6]

The duotone technique is used for high quality single-color prints, such as books for exhibitions, expensive photography books, and high-quality post cards. The duotone technique requires accurate registeration and good press control. Lithography has been the main choice for duotone reproductions. Because of low capability in these requirements, the double-impression duotone technique has been seldom used by flexographic printers. However, this researcher believes that the duotone technique may make it possible for the flexographic process to produce finer print resolution and longer tonal ranges. This research will investigate the use of two printing plates requiring different pressures between the plate and the impression cylinder for the highlight and shadow plates, to produce a longer tonal range and a better reproduction capability than

that of a normal duotone technique with applying the same pressure for both plates.

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CHAPTER II

Literature Review

Darkness Quantifications

When a black-and-white image is reproduced, the different brightness among different parts of the original are called "tone."[1] Tones of an image are associated with the intensity of the light that any given surface directs to the eyes. A reproduction process must simulate sufficiently well the tones of the original image.

A measurement method is required to quantify the tones. In the graphic arts and photography field, "density" is widely used. The density is defined as

$$\text{Density} = \log (1 / \text{Reflectance}) \text{ for reflection density}$$
$$= \log (1 / \text{Transmittance}) \text{ for transmission density}$$

* Reflectance (Transmittance) ......
The ratio of the reflected (transmitted) to initial illuminance.

However, the sensitivity of the human eye to brightness is not in proportion to the density. The Munsell value was the first system to linearize the data between density and human sensitivity of brightness, using a series of gray patches.[2] However, in later studies, it has been proven by C. J. Bartleson and E. J. Breneman that the human sensitivity to the

brightness in a complex scene is not the same as that of a simple gray patch. They defined the Bartleson and Breneman value (the B & B value) to linearize the darkness to the human visual perception. The B & B value is interchangable with the density value and the Munsell value.[3]

$$\text{The B \& B Value} = 116 - 11.5 \{ [10 \hat{} (2 - D) + 1] \hat{} 0.5 \}$$

$$\text{The Munsell Value} = 4.85 \operatorname{arccosh} \{ 1 + [(102.56 (10 \hat{} -D) / 34.26] \}$$

These values are useful for different purposes when the analysis and evaluation of reproduction are required.

Tone Reproduction

The production of the halftone image is an important step in the prepress operation because it accounts for the printing characteristics of the flexographic process. This function is refered to as tone reproduction. Because flexography is a relief printing method, it is impossible to lay down varying densities of ink.[4] Consequently, a halftone process must be applied to reproduce a continuous-tone image. Several methods can be applied for the conversion process from continuous tone to halftone. (Appendix B for halftone conversion methods)

A contact screen is often used for black-and-white photographs because of its low cost. A good reproduced halftone image requires controlling the density patches of highlight, middle tone, and shadow area, called Three Point

Control. This process is accomplished with three exposures, the main, bump, and flash exposures.

Main Exposure.....Highlight-detail exposure made through the lens and a halftone screen.

Bump Exposure.....Image exposure without a screen made through the lens, used to change contrast by compressing the screen range.

Flash Exposure....Non-image exposure made on the film through a halftone screen. It regulates detail in the shadow area.

More critical tone reproduction can be expected using an electronic color scanner rather than using a contact screen because of additional two point control, at the range of 25 percent and 75 percent, with the three point control of a contact screen.[5]

As mentioned before in the introduction, the density range of a single impression is shorter than that of the original. The density of the shadow area is compressed to meet the same density range as a single impression ink density. The area reflecting the most light is the highlight area which has the smallest printed dot. The least light reflected area is the shadow area which has the largest printed dot.

Three curves are shown in Figure 2. The 45 degree straight line (A) is a facsimile tone reproduction curve.[6] Because the density range of one ink layer is limited, it is physically impossible to reproduce the straight-line tone reproduction curve with one layer of ink. Therefore, the density range of the original image has to be compressed somewhere to meet the basic density range of ink.[7]

The steeper the slope of the curve at any given point, the better rendition of detail or tone reproduction at that

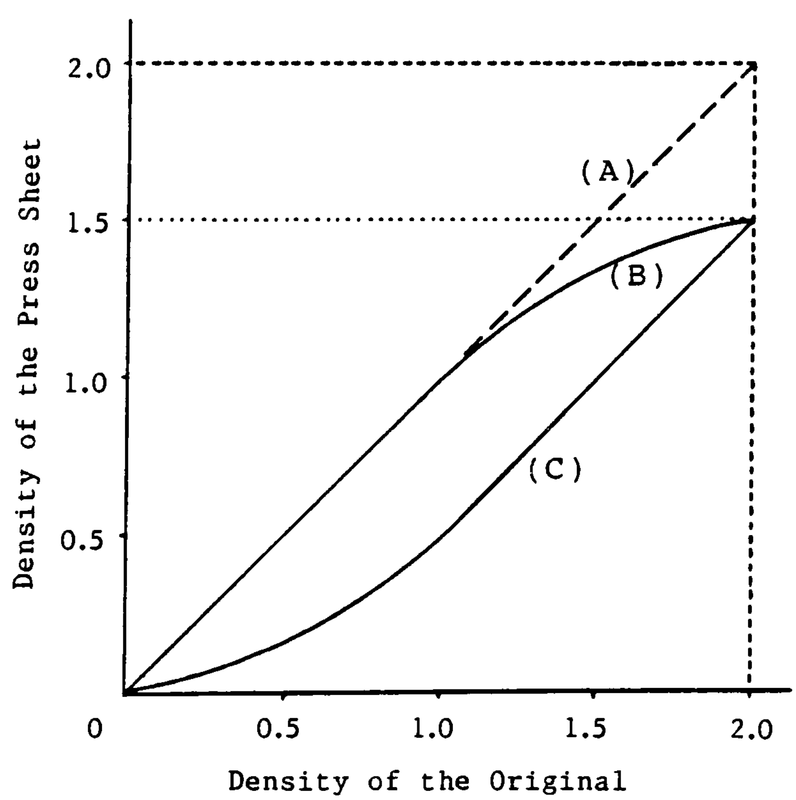

Figure 2. Black-and-white Tone Reproduction Curves

point.[8] Curve (B) shows highlight to middle tone similar to the ideal curve, 45 degree angle, which gives a good highligt contrast and loss of shadow contrast. Curve (C) represents a tone reproduction whereby the middle tone and shadow are enhanced. The preferred curve shape is determined based upon the type of original picture.

Duotone Printing

Duotone Black, Double Dot Black, or Double Impression Black is one of many duotone print techniques. THE PRINTING INDUSTRY[9] defines duotones as:

> . . . reproductions of black-and-white photographs for which two closely related color inks, or even two black inks, are used. The original picture is photographed twice; one negative emphasizes the highlights, the other the shadows of the picture. Two image carriers are made, one from each of the two negatives, and the picture is printed with two different inks either of the same hue or of two carefully chosen related hues, one lighter and the other darker.

GRAPHIC ARTS MANUAL[10] adds:

> Duotones are used mainly in letterpress and lithography. They are not needed in conventional gravure, as single-color prints have a tonal range equivalent to and exceeding photographic images without the danger of set off.

In gravure printing, the ink density can be controlled not only by the ink itself, but also through the cell depth of the gravure plate cylinders. While flexographic inks are the same type as gravure inks, flexography is a relief process which can hold and transfer only limited amounts of ink,

unlike that of gravure. This researcher was unable to find any references in the literature to the use of the duotone technique used in flexography.

Although many variations are involved in duotone printing processes, the only things that can be standardized are the screen angles which are positioned 30 degree apart to reduce moire pattern.[11] A less apparent rosette pattern of dots can be achieved by different screen rulings for the two negatives.

Although duotones are mainly classified into two categories, two-color process and double-impression black, (Appendix C for more information for duotone printing processes) the porposes of these duotones are:

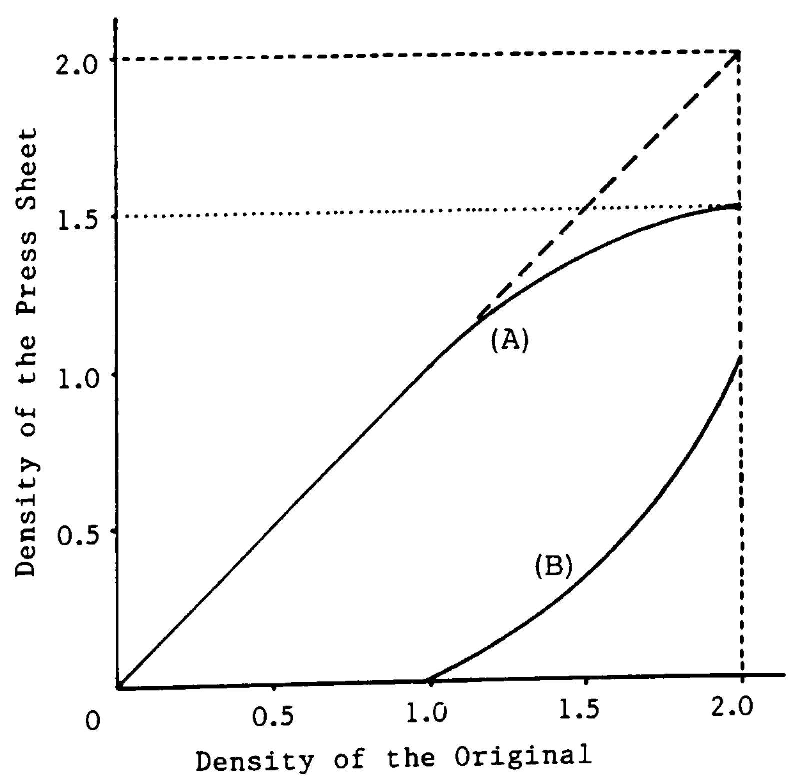

Figure 3. Schematic Duotone Reproduction Curve

1. To extend the density range.
2. To create artistic special effects.
3. To give a better potential to achive higher image quality than a monochrome reproduction.

Two curves are shown in figure 3. Curve A is the tone reproduction curve, which an ordinary single impression plate can reproduce. An additional impression is required to increase the maximum ink density. The ink density of curve B is overprinted on that of curve A. Therefore, the total density range is extended by the two ink layers.[12] This phenomenon has been proven with lithography and letterpress. Although the type of ink in lithography and letterpress differs from a flexographic ink, the same results can be expected.

When the total density of two ink layers is calculated, it is theoretically a sum of the two ink densities. However, the calculation does not work in actuality. It has been proved with the "additive failure" by J. A. C. Yule. The following are the major causes of additive failure: first-surface reflection, multiple internal reflections, ink opacity, trapping, back-transfer effects, spectral characteristics, and halftone structure.[13] However, when two layers of the same fluid inks are used, the effects of back-transfer, trapping, and spectral

characteristics are negligible. (Appendix D for the additive failure for flexographic inks)

From a combination of these factors, a simple addition of two ink layers cannot apply for the total density of duotones. For the practical calculation of the total ink density, a duotone diagram is applied. This diagram is explained thus:

> It consists of two halftone scales situated 90 degrees apart in its step orientaion and 30 degrees apart in its screen angling orientaion. The first impression scale is placed at horizontally, and the vertically incremented scale as the second impression. Each impression samples a full range of tones from those equally incremented halftone steps for each given ink.[14]

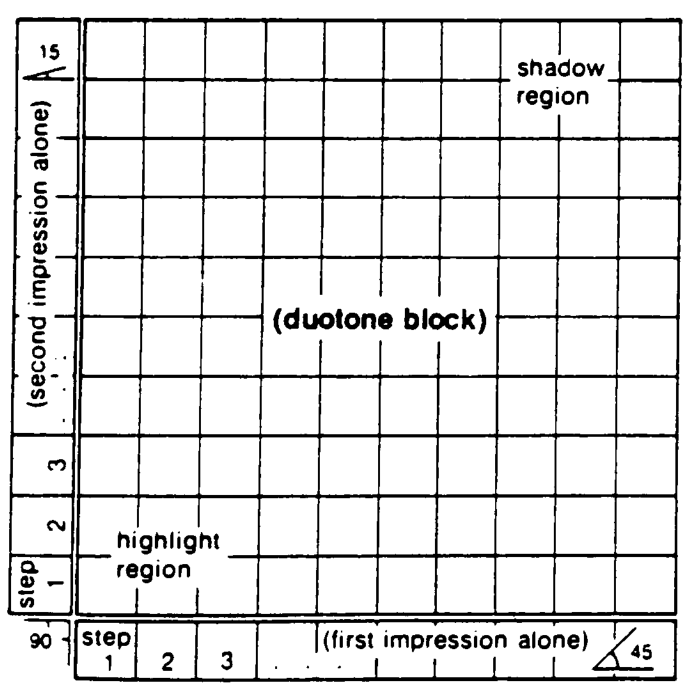

Figure 4. Duotone Diagram[15]

The feature of this test is being able to produce the same visual density with different pairs of halftone tints. This diagram can be combined with the tone reproduction curves for duotones to obtain a reasonable result. This diagram can be applied for only a specific ink, paper and press condition.

Moire Patterns

When two periodic frequencies of nearly the same structure are superimposed, a third periodic pattern is occured, called moire patterns. Moire pattern is a undesirable extensive pattern in print reproduction process.

Although there are many causes of moire patterns, a basic reason can be explained by using a parallel line that the contrast between areas where the dots are superimposed and these where they are juxtaposed.[17] (Figure 5) When a moire pattern in screen tints are concerned, the frequency of the periodical different spacing may occur in four directions.

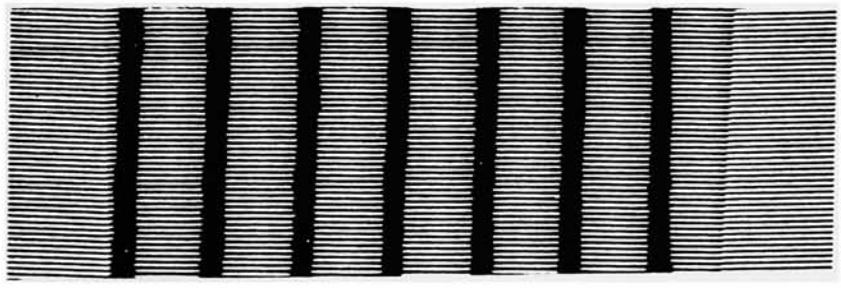

Figure 5. Moire Pattern by Two Parallel Line[18]

According to the PRINCIPLES OF COLOR REPRODUCTION, the period (K) of the moire pattern can be expressed as:

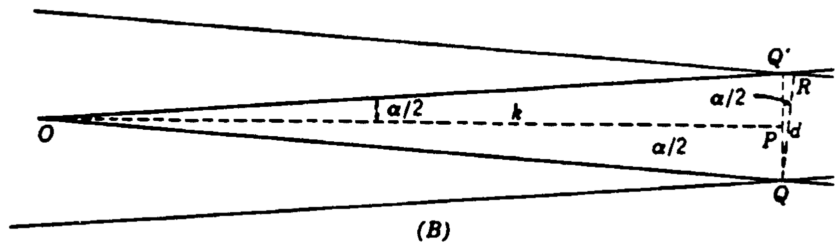

Figure 6. Geometrical Relationship in the Moire Pattern by Two Parallel Lines[19]

$$K = \frac{d}{2\sin(a/2)}$$

d ; the period of the parallel screen tints.
a : the range for the separating angle.

The results show where (a) = 0, (K) $=\infty$, which represents the moire pattern is so large that it cannot be seen. From this phenomenon, the best way to avoid moire patterns would be to print all the halftones at the same angle, however, it is not a practical application. At the angle of 30 or 60 degrees, the period of the moire pattern is the multiples of the period of the parallel tints, otherwise, it is hardly visible.[20] This is the reason the screen ruling for duotone prints should be positioned at 30 degree apart.

In flexography, the screen angle is sometimes different when a mechanically engraved anilox roller is used because a worn anilox roller can cause the appearance of a moire pattern.

The appearance of moire patterns will be more critical when a third screen tint is used. However, it can be ignored in this experiment because of the use of only two impressions.

Flexographic Plates

Although the characteristics of rubber and photopolymer plates are often contrasted, these two plates have a similar structure which is composed of polymers.[21] Heat and pressure need to be applied for rubber to cause polymerzation, which is known as vulcanization, while UV light energy is applied for photopolymer. Polymers are formed by small molecules (monomers) reacting together to form a large molecule.[22] The reaction system for flexographic plates can be explained with "addition polymerization," which is the combination of monomers by reaction of carbon to carbon double bonds.[23] Some mechanical characteristics can be considered for these plate materials.

Plate Shrinkage

Although both rubber and photopolymer have a similar structure, only rubber compounds shrink after the vulcanizing or molding process. Generally, most rubber presently used for plates has a shrinkage factor ranging between 1.5 to 2 percent, even though the shrinkage depends on the grain direction and the type of rubber. The shrinking factor also influences the plate height. The consistency of plate heights is important. A photopolymer plate has a higher capability of consistency. One source points out that the uniformity of plate thickness is ±0.0005 inch within sheet, ±0.001 inch with sheet to sheet.[24] A rubber plate has an average consistency of ±0.02 inch. There is a variety of plate thickness for different methods and machines in flexography, such as

Plain rubber plates .... 0.107 inch
Label plates .... 0.067 inch
Newspaper .... 0.020 inch
Corrugated board .... 0.250 inch

Fluidity

One of the prime features for rubber and photopolymer is elasticity (or resiliency) which is the property of being able to recover its size and shape after deformation. The

following phenomenon explains the reason of excessive impression which causes the dot gain and fill-in problems.

> Applying pressure to the material changes its shape but its volume . . . . the amount of compressed material follows the lines of least resistance, billowing out and away from the point of pressure and popping up adjacent to the concavity.[25]

Elongation

Elongation is common to all rotary printing processes with relief plates. When a plate is mounted around the cylinder, the plate stretches, causing its print to get longer. The plate width across the cylinder does not widen. This is termed elongation. The amount of elongation depends on the plate thickness, the degree of curvature, the depth of relief, and the relative openness of the plate surface.[26]

The amount of elongation can be determined by experiments and formulas. Although different formulas for elongation have been developed, there is a mathematical formula for elongation (E) of relief plates:[27]

$$E = 1 + \frac{\Delta r}{r}$$

r ; the cylinder repeat length
Δr ; the plate thickness

When elongation occurs, the plate height must be changed because of simple mathematics. If a plate is considered as a cube,

$$(\text{Volume}) = (\text{Length}) \times (\text{Width}) \times (\text{Height})$$

Volume and width are constant; therefore, when the repeat length is increased, the height must be decreased.

From experiments, it has been observed that the plate height in the highlight area is higher than that of the shadow area because of the difference in the relative openness of the plate surface. Therefore, when the relief areas in the shadow area receive enough pressure to transfer ink properly, the relief areas in the highlight area receive excess pressure. As a result, flexography has more dot gain in highlight areas compared to ordinary printing methods. The calculation of the required plate height decrease has not been developed because of the many variables in flexographic plate structures, materials, and thickness.[28]

Another phenomenon also causes a decrease plate height consistency. (Figure 6) When a material (A) is bent on the curved plane (B), the force which pulls (A) is not even. The center of the raised surface receives the largest force which becoming less on the outside to the edge of the raised surface. Therefore, the surface of plates has a slightly concave shape. This phenomenon, known as

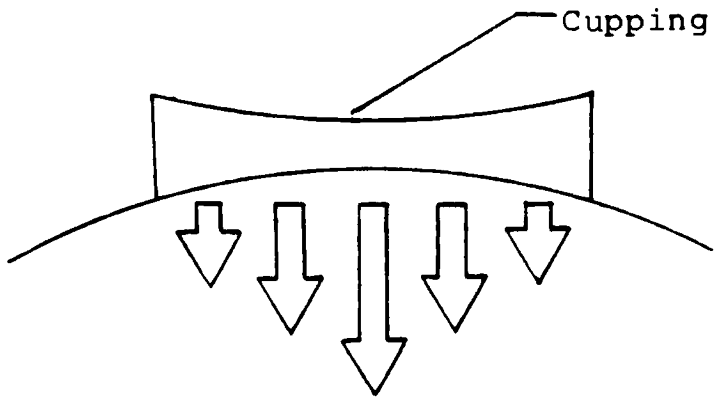

Figure 7. Diagram of "Young's Modulus"

"Young's Modules,"[29] affects the image area of flexographic plates and is termed "Cupping" in flexographic industry.

Cupping can often be observed in solid areas. The back-side of flexographic rubber plates are somethimes ground down to even the plate height aberration after the vulcanization process. Because the plate is bent in the opposite direction during the grinding process, the degree of cupping can increase. (Figure 7) As a result, the dot gain curve in flexography is slightly different from that of ordinary printing methods which have more dot gain from highlight to middle tone areas. The amount of dot gain is directly related to the pressure between the plate and the impression cylinder. Greater pressure causes more dot gain. The peak of the dot gain curve tends to shift from middle tone to highlight areas by the excess pressure between the anilox roller and the plate cylinder.

Because of these defects just described, a small range of dot size which directly relates to a limited density range is available in highlight areas where the human eye is most sensitive. Most highlight dots also shift to middle tone areas where the largest optical dot gain occurs. This phenomenon can be one of the main problems in flexography.

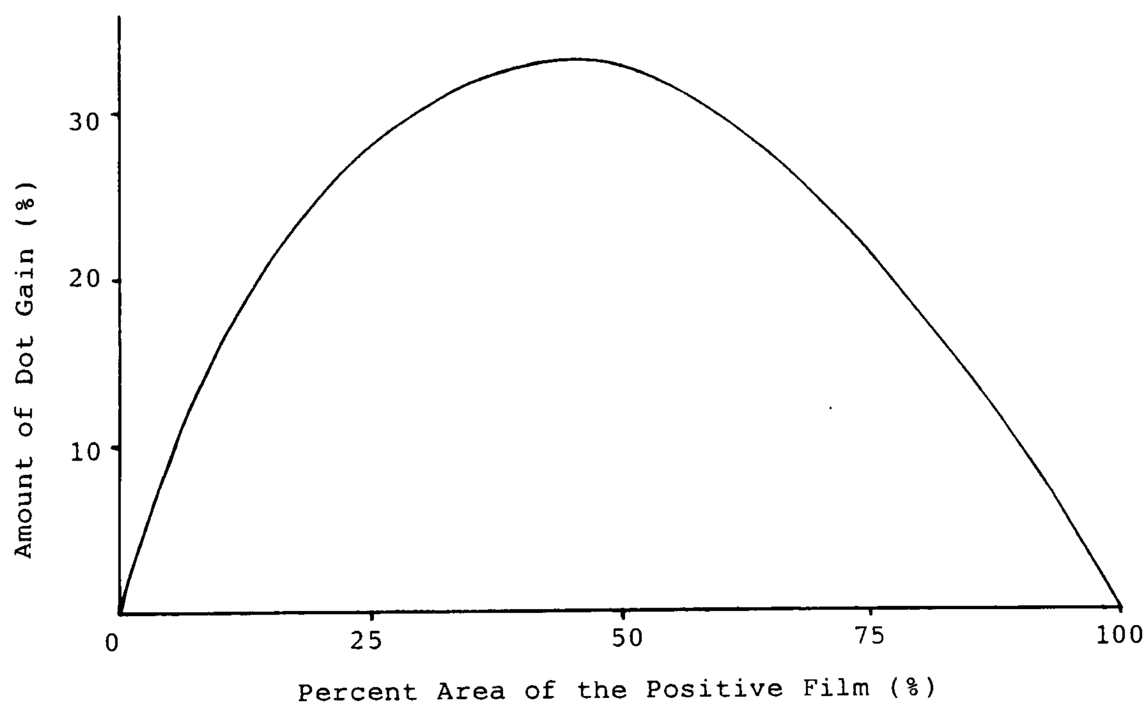

Figure 8. Dot Gain Curve in Flexography

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CHAPTER III

Hypothesis

Hypothesis:

When a double-impression duotone is applied for flexography, the use of a different amount of pressure between the plate and the impression cylinder will result in improved Tonal Rendering Characteristics as compared to using equal pressure for both image carriers.

For the purpose of this study, Tone Rendering Characteristics are defined as:

(1) The darkness range of the reproduction,

(2) A determination of the smallest highlight dot that can be held on the press sheet,

(3) The determination of the maximum shadow density by two impressions,

(4) Smoothness of gradation in lighter tone values without causing a roughness, unpleasant harshness or spots in the tonal rendering of reproduction,[1] and

(5) The consistency of the reproduction during the press run.

ENDNOTES 3

1. Babcock, Philip. "Webster's Third New International Dictionary." Springfield, MA. Grove G. & C. Merriam Comp. 1968 p2152

CHAPTER IV

Methodology

The experimental tests can be divided into two categories to evaluate the effects of two kinds of duotones. One is the test using the Duotone Diagram, mentioned on page 16. The second test is the evaluation of a halftone picture image, which will be explained on page 31.

Duotone Diagram

The duotone diagram will be printed to obtain the press characteristics of a specific ink and substrate with a specific press station. This diagram can be used to optimize the tone reproduction data for a pictorial image. An RIT symmetrical scale and a highlight and shadow scale will also be used. In this test, the pressure between the plate and the impression cylinder will be the only variable. All other aspects of the test will remain constant.

Technique 1.

An adequate amount of pressure, which can print the complete gray scale of the Duotone Diagram from highlight to shadow area, will be applied for both printing plates.

Technique 2.

A light amount of pressure will be applied for the first impression of the Duotone Diagram. Only the film dot size from 1 to 25 percent will be considered to avoid the excess pressure caused by the plate height tolerance. The same amount of pressure as used in technique 1 will be applied for the second impression.

From these two tests, the following factors will be evaluated:

* Darkness range
* Capability of the smallest printed dot size.
* Dot gain
* Consistency of Reproduction

Consistency of Reproduction

Consistency of reproduction will be measured to substantiate the reliability of this experiment. Printed gray scales will be applied for this test. Three patches will be chosen from highlight, middle tone, and shadow areas. (The middle tone and shadow patches may be overprints of two impressions.) After the press run, 31 press-sheets will be garthered randomly, and densities of the selected three patches will be measured. These data will be analyzed, using the F-TEST (THE VARIANCE RATIO TEST).[1]

$$F = \frac{Sx1}{Sx2}$$

A larger standard deviation, calculated from each density data, will be selected as Sx_1, thus a smaller number of standard deviation will be Sx_2.

Visual Judgment

Two different pairs of tonal reproduction curves will be considered. One is for a normal duotone technique, and second is for the experimental duotone technique for flexography. (Figure 9 on page 32)

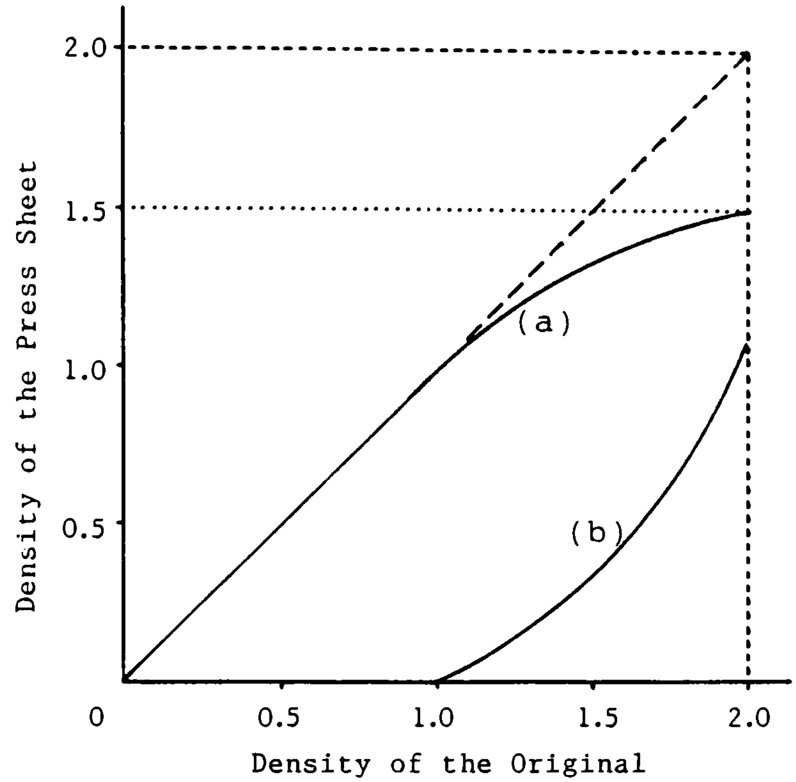
TRC-1. A Normal Duotone Tone Reproduction Curve (Figure 9-1)

* The first impression contains a normal single-impression tone reproduction curve (a) from highlight to shadow. The curve from middle tone to shadow is compressed to meet the solid ink density of the printing system.
* The second impression (b) will print from middle tone to shadow in an attempt to make up for a lack of density from the first ink layer.

TRC-2. The Experimental Duotone Tone Reproduction Curve (Figure 9-2)

* The first impression (c) will accurately reproduce the density range from highlight to the point (z), which is equivalent to the 25 percent film-dot size. A twenty-five percent dot area will be printed above point (z).

9-1. A Normal Duotone Tone Reproduction Curve (TRC-1)



9-2. The Experimental Duotone Tone Reproduction Curve (TRC-2)

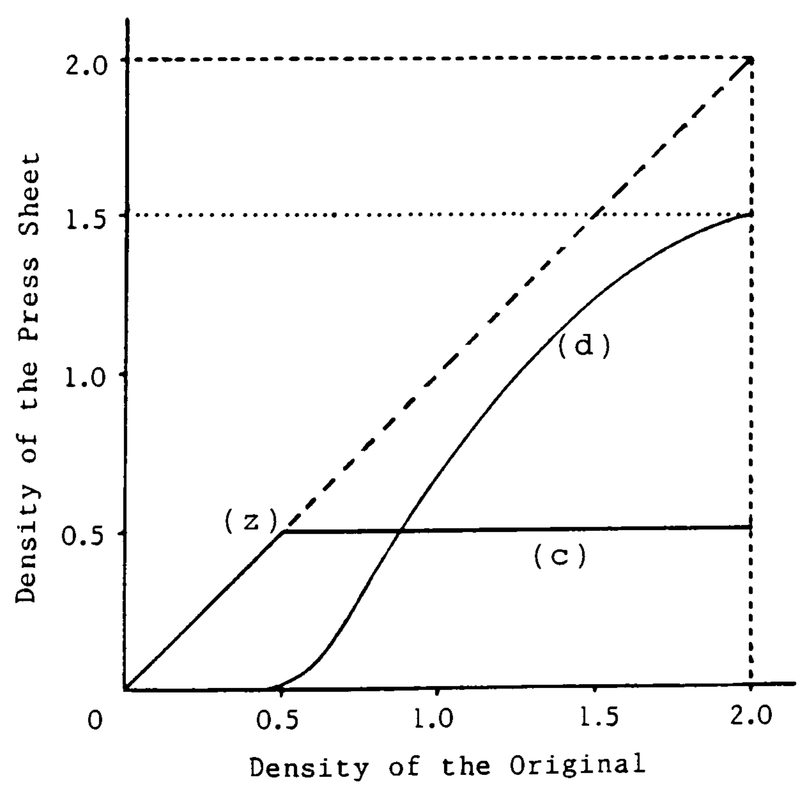


Figure 9. Two Pairs of Duotone Reproduction Curves

* The second impression (d), will start at the point (z), and will increase the density and tonal range from that point to the desired density. This will add image detail between the point (z) and the shadow area.

These two pairs of duotone techniques will reproduce as closely as possible to the 45 degree straight line total tone reproduction curve. Their required camera curves for each impression will be determined, based upon the data in the duotone diagrams, using the Jones diagram. (Figure 10)

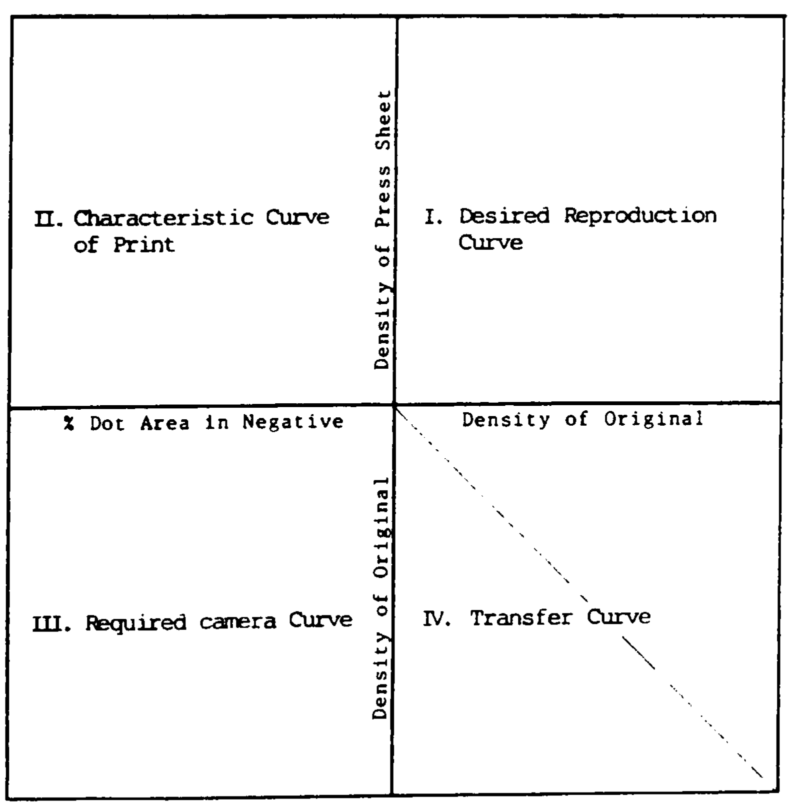


Figure 10. The Jones Diagram

There are two variables in this study, the pressure between the plate and the impression cylinder, and the tone reproduction curves. Therefore, four possible reproductions must be considered.

(A). TRC-1 applying Technique 1.

(B). TRC-2 applying Technique 1.

(C). TRC-1 applying Technique 2.

(D). TRC-2 applying Technique 2.

After the press run, a sample will be taken from each roll. Thirty observers will view the four printed images under the standard viewing condition (5,000 degree Kelvin) to compare the four different techniques. The total of six pairs of images will be judged by each observer. The comparison will be done, choosing "a better print" subjectively. The basis of judgment will be "a smoothness of tonal rendering. ("a smoothness of tonal rendering" is defined in page 27) The results will be evaluated with the PAIRED-COMPARISON TEST[2] for determining the smoothness of tonal rendering characteristics.

Pictorial Image

A continuous tone photographic print will be prepared. The image will contain a long tonal range with fine detail. For ease of judgment, the image will have a smooth gradation of light tonal value from highlight to shadow.

The Total Tonal Rendering Characteristics

The total tonal rendering characteristics will be determined by the data, discussed in this chapter. Although there are many methods of determining the results of this experiment, the PRINT QUALITY INDEX[3] will be used. Because this test is simple and flexible, it can be adapted to many situations.

The data must be classified, depending upon the degree of its significance or seriousness. In this experiment, an advantage of one technique can be considered as a defect of the other. The defects are classified into two categories, Major defects and Minor defects, which will determine the degree of deficiency.

$$\text{Print Quality Index} = 10 - (5a + b)$$

a; The total number of major defects
b; The total number of minor defects

This test is based on the assumption that a major defect is five times as severe as a minor defect. A higher index indicates better total tone rendering characteristics. The index can be negative.

Measuring Instruments and Expressions

Because the black-and-white image is reproduced in this research, a reflection densitometer with visual density filter will be used to collect data. X-RITE 309 Graphic Arts Densitometer in the School of Printing Management and Science will be used consistently to avoid the inter-instrument aberrations.

The densitometer will be calibrated with the attached calibration plaque. After the densitometer is calibrated, data will not be gathered for at least three minutes until the equipment is stablized.

The Bartleson and Breneman value will be given priority over the density value for the expression of darkness whenever human sensitivity is more relevant than physical measurements. For tone reproduction curves, the density expression will be used because it is the most frequently used expression in the graphic arts industry. Otherwise, the B & B value is calculated from the density value, using the formula discussed on page 10.

The following factors have been held constant to minimize the variables for this experimental work:

Screen Ruling ..... 100 lines per inch

Screen Angle ...... +18 degree for the first impression and
-18 degree for the second impression

Press Speed .... 75 feet per minute

Plate and Plate thickness .... Photopolymer plate, 0.067"

Ink Viscosity ..... 45 sec. with #2 Zahn cup (17 sec. with #3 Zahn cup)

Equipments and Materials

Kodak 324 Automatic Film Processor
40 lds Coated Paper
X-RITE 309 Graphic Arts Densitometer
Hell DC-300 BL Scanner
Flexographic Press for Label Printing (Mark Andy 4120)
Kodak ES Scanner Film
Magnifying Glass
Matte Surface Contact Film (Du Pont)
Photopolymer Plate (Du Pont Cyrel Plate)
Photopolymer Plate-making Equipment (Du Pont System)
Plate Mounter (Mark Andy Optical Mounter)
Polyamide Ink (black)
RIT Symmetrical Scale
RIT Highlight & Shadow Scale
3M Sticky Back
Transparency Gray Scale
Zahn Cup (#2 & #3)

ENDNOTES 4

1. Afifi, A. A. and Azen, S. P. "Statistical Analysis. Computer Oriented Approach." New York, NY. Academic Press Inc. 1972 p183

2. "Manual on Sensory Testing Methods, ASTM Special Technical Publication 434." Philadelphia, PA. American Society for Testing and Materials. 1968 p64

3. White, C. Ian. "The Print Quality Index." TAGA Proceeding. Rochester, NY. Technical Association of Graphic Arts. 1975 p259

CHAPTER V

Analysis of Data, Part 1

Dot Gain

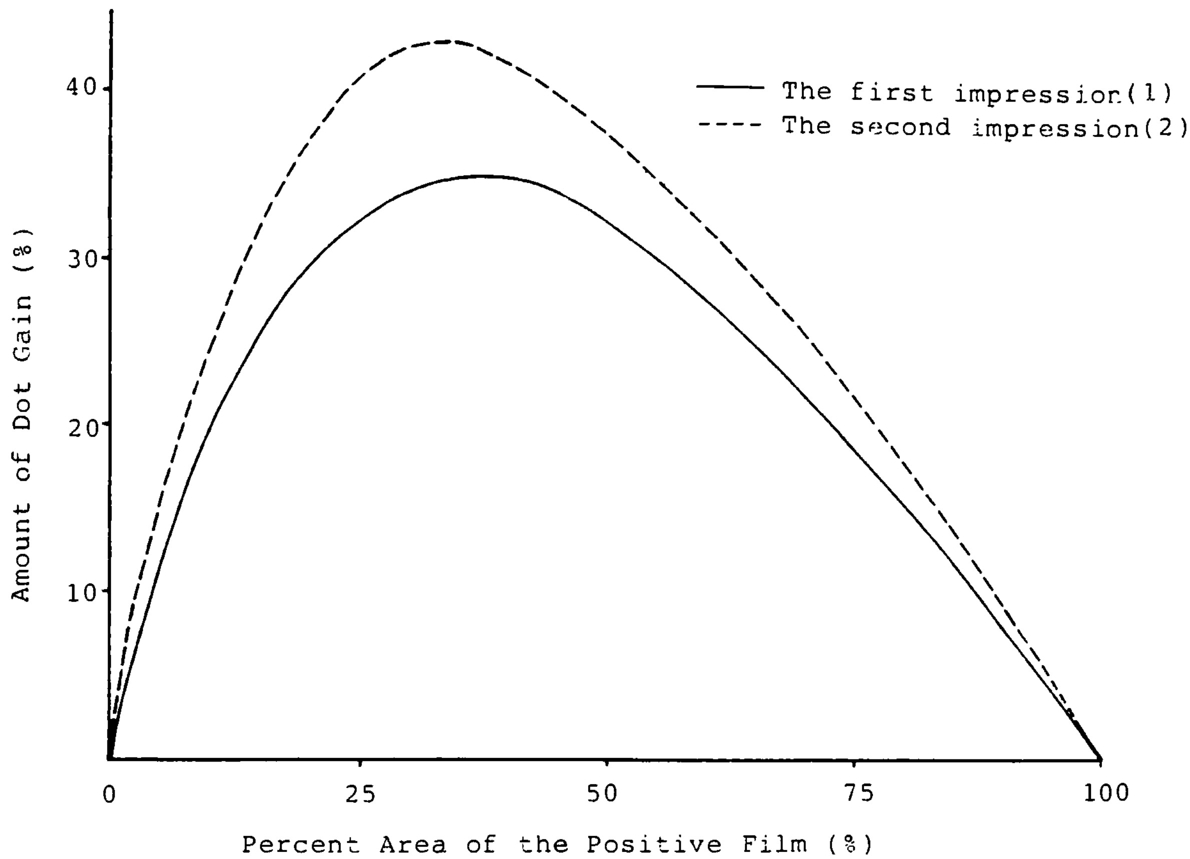
The results of the dot gain test for the first and the second impression for both technique 1 and 2 are illustrated in Figure 11. When dot gain curve #1 for Figure 11-1 and 11-2 are compared, the curve of technique (2) indicates less dot gain than that of technique (1) in highlight area. Although it was mentioned in chapter 2 on page 22 that the print smoothness of the highlight area is a problem in flexography, less unwanted dot gain was determined by the results of technique (2).

The curve #2 for Figure 11-1 and 11-2 indicate a similar curve shape by both techniques (1) and (2), even though curve #2 has more dot gain than curve #1. These facts would support the reliability of the test data.

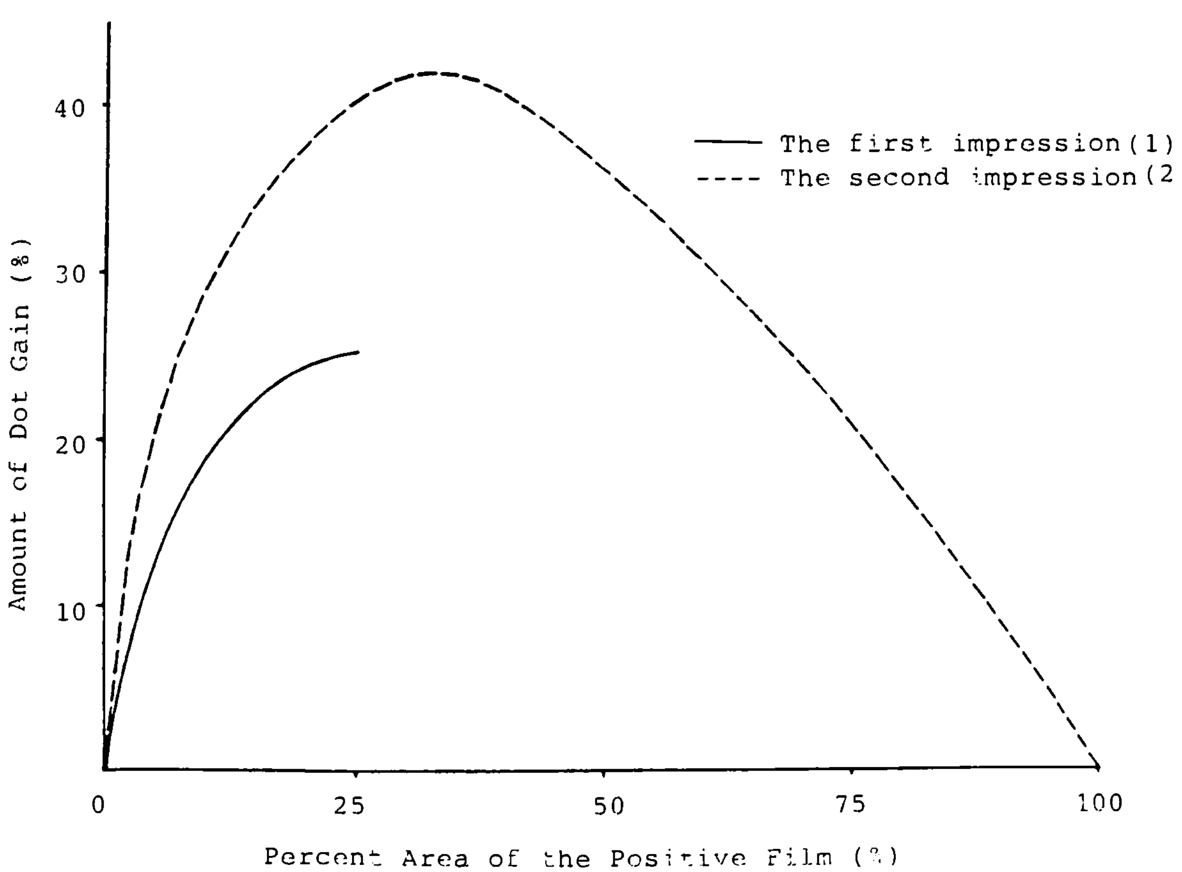
Capability to Print the Smallest Highlight Dot

Because of less dot gain in highlight areas, technique (2) has a better capability than technique (1) to print the smallest highlight dot. When technique (1) was applied, the size of the 1 percent dot in the original film became 13

11-1. Dot Gain Curves of Technique 1.



11-2. Dot Gain Curves of Technique 2.



percent in the reproduction. A 3 percent printed dot was obtained when technique (2) was applied. This darkness difference of the smallest dot between technique (1) and (2) is 0.06 in the density measurement, and 7.54 in the B & B value.

Darkness Range

The data in Table 1 were obtained from this experiment. In the density measurement, technique (1) has a higher range than technique (2). However, technique (2) has a slightly higher range than technique (1) in the B & B value. It is concluded that a visually wider range can be expected in technique (2). Thus, technique (1) has a higher maximum darkness value.

		Technique 1	Technique 2
Minimum Darkness	Density	0.10	0.04
	B & B	12.86	5.58
Maximum Darkness	Density	2.16	1.71
	B & B	104.04	96.30
Darkness Range (B & B)		88.18	90.72

Table 1. Darkness Ranges

Isodensity Curves

In both techniques (1) and (2), it is concluded that these isodensity curves[1] are close to the 45 degree angle because of their nearly 100 percent trapping. The curve is slightly steeper than the 45 degree straight line because the second impression has more dot gain.

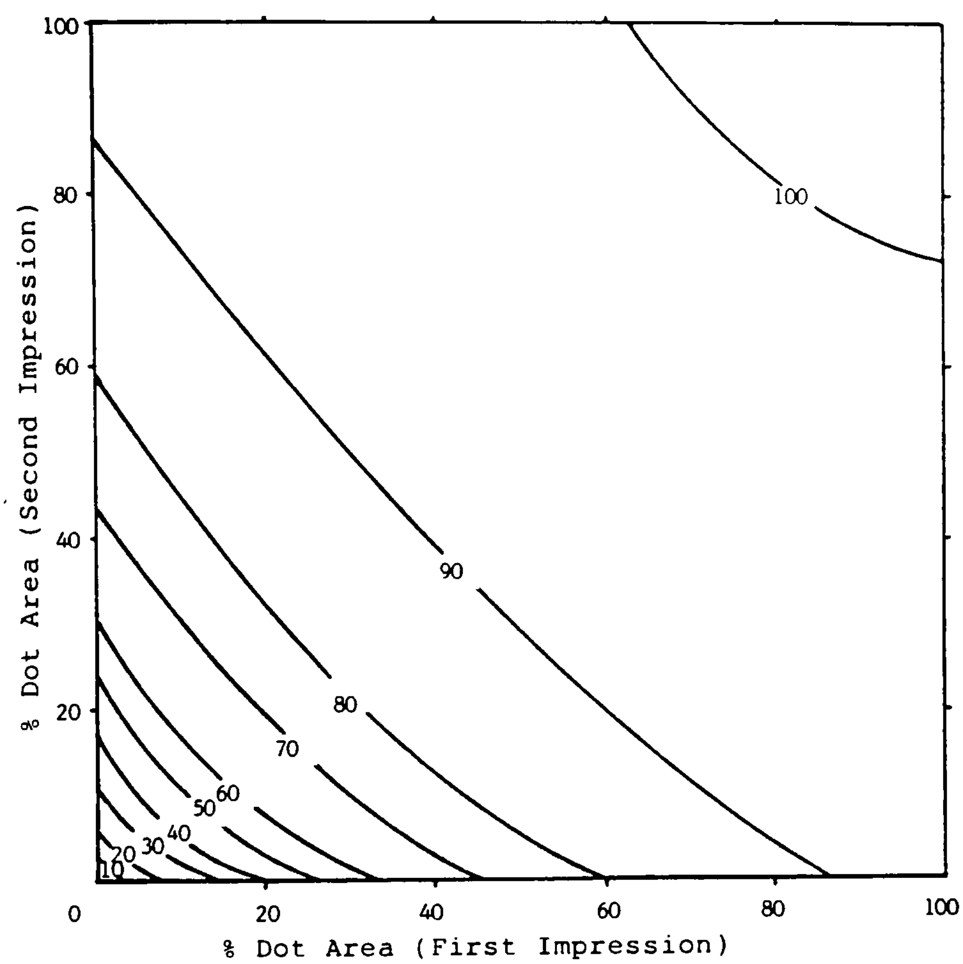
When space between isodensity lines in highlight areas is noted, technique (2) has more space than technique (1), which represents the possiblilty of reproducing better highlight image by using technique (2).

Wide space can be seen in shadow areas (90 to 100) in technique (1), which represents the possibility of reproducing a better shadow image by using technique (1).

Consistency of Reproduction

Three patches were chosen from the density value of 0.2, 0.8, and the Maximum Density in the each gray scale. Although the average of these density values between technique (1) and (2) has some tolerance, this tolerance is negligible because their standard deviations were compared instead of their density numbers. The data were evaluated at 95 percent significant level.[2] (The data are in Appendix E and the results are on page 44)

12-1. Technique 1.



12-2. Technique 2.

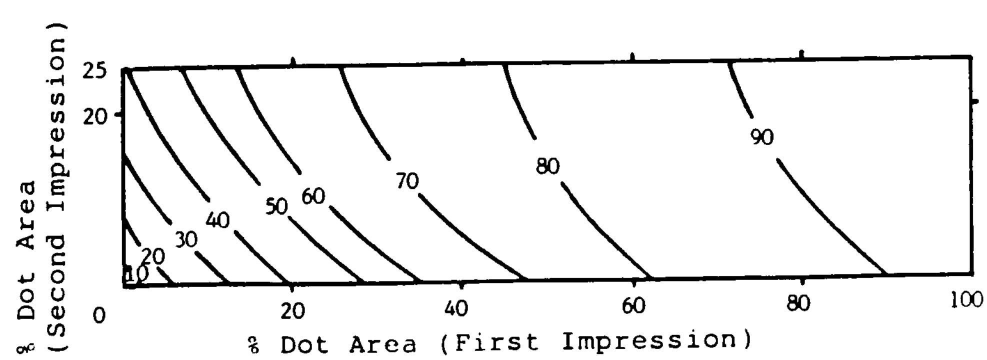


Figure 12. Isodensity Curves in the Bartleson and Breneman Darkness Value

The VARIANCE RATIO TEST

--- Highlight --------

Technique 1 ... $x_2=0.101$, $Sx_2=0.0072$

Technique 2 ... $x_1=0.079$, $Sx_1=0.0113$

$$F = \frac{(0.0113)^2}{(0.0072)^2} = 2.46 > 1.84$$

H_0: $x_1 = x_2$ was rejected (H_1: $x_1 > x_2$ was accepted)

--- Middle tone ------

Technique 1 ... $x_1=0.634$, $Sx_1=0.0816$

Technique 2 ... $x_2=0.797$, $Sx_2=0.0620$

$$F = \frac{(0.0816)^2}{(0.0620)^2} = 1.73 < 1.84$$

H_0: $x_1 = x_2$ was accepted at 95% significant level

--- Shadow -----------

Technique 1 ... $x_2=1.633$, $Sx_2=0.0235$

Technique 2 ... $x_1=1.437$, $Sx_1=0.0291$

$$F = \frac{(0.0291)^2}{(0.0235)^2} = 1.53 < 1.84$$

H_0: $x_1 = x_2$ was accepted at 95% significant level

The results show that technique (2) has obviously more variability than technique (1) in the highlight area. No significant difference was observed between technique (1) and (2) in middle tone and shadow areas.

The reason can be that less pressure applied for technique 2 was not enough to transfer a constant ink-film thickness even in the highlight area. (However, the question of whether the tolerance obtained from technique (2) affects a significant difference in the pictorial image is not studied in this experiment.) It can be concluded that the consistency of highlight reproduction with technique (2) is not as good as that of technique (1).

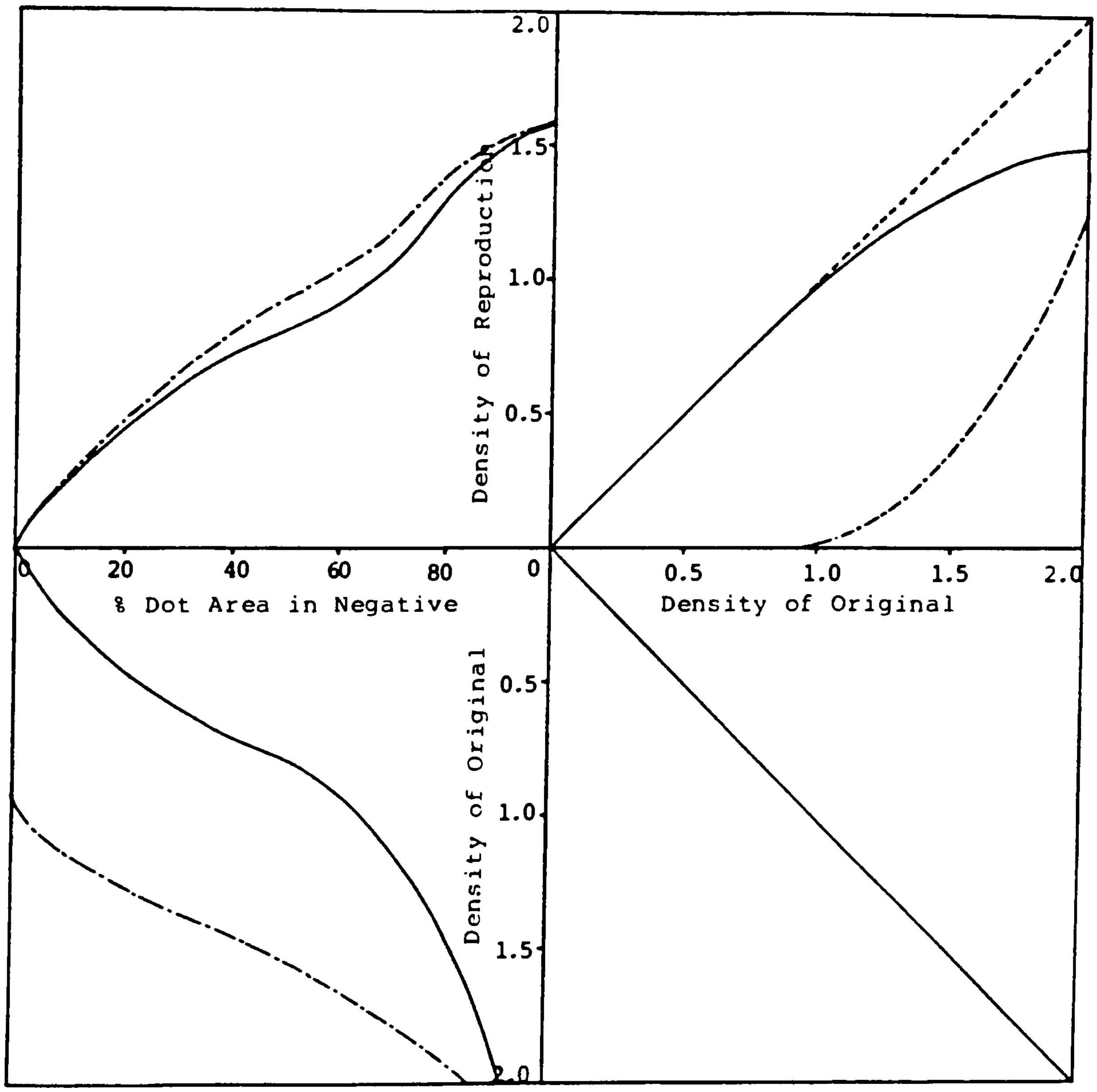


Figure 13. The Jones Diagram for Reproduction (A) & (C)

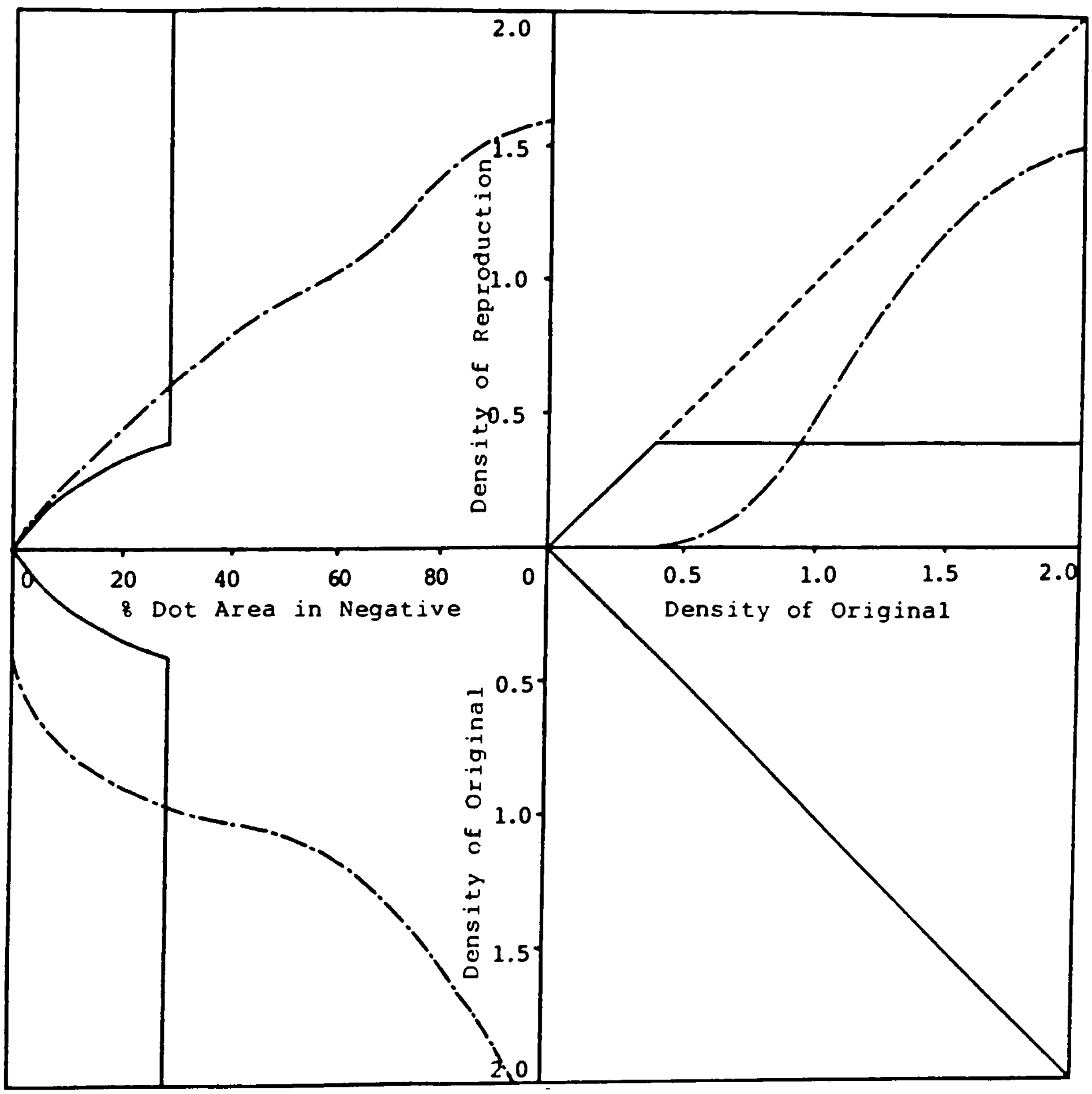


Figure 14. The Jones Diagram for Reproduction (B) & (D)

ENDNOTES 5

1. Chung, Y. Robert. "Tone and Color Control in Duotone Reproduction". TAGA Proceeding, Rochester, NY. Technical Association of Graphic Arts Inc. 1979 p38

2. Afifi, A. A. and Azen, S. P. "Statistical Analysis. Computer Oriented Approach." New York, NY. Academic Press Inc. 1972 p183

CHAPTER VI

Analysis of Data, Part 2

Evaluation of Smoothness

Four different duotone images were reproduced, following the four techniques described in the methodology. Although two pairs of tone reproductions were made accurately, according to the data from the duotone diagrams, these printed samples have some defects, such as gear streaking marks, moire patterns, and different maximum densities. These defects cannot be eliminated because of the press limitations and the nature of screen ruling. Although the press sheets show some minor printing defects, they did not detract from overall reproduction needed for the judgment of smoothness.

Moire patterns were observed in all images because of a difference in screen ruling and angle. Although both of the screen rulings were set in 100 lines per inch, the actual screen rulings were 110 and 100 lines per inch because of the design of HELL DC-300BL scanner. The appearance of a moire pattern in the reproduction (A) and (C) was more noticable than that of the reproduction (B) and (D) because (A) and (C) had a lighter middle tone in the reproduction. (Figure 15 on page 50)

15-1. The Press Sheet Sample for (A)

15-2. The Press Sheet Sample for (B)

15-3.

15-3. The Press Sheet Sample for (C)

15-4. The Press Sheet Sample for (D)

Smoothness of tonal rendering was judged by thirty observers (The data are shown in Appendix F). The data were analyzed based upon the PAIRED COMPARISON TEST. The result was:

(A)-(B)	(A)-(C)	(A)-(D)	(B)-(C)	(B)-(D)	(C)-(D)
26-04	29-01	22-08	23-07	18-12	04-26

* The critical number at 95% significant level ... 21/30[1]

Therefore, it is concluded that

(A) > (B) = (D) > (C)

(A). TRC-1 applying Technique 1.

(B). TRC-2 applying Technique 1.

(C). TRC-1 applying Technique 2.

(D). TRC-2 applying Technique 2.

(These techniques are explained at page 29 to 33)

The data did not prove the hypothesis. The main reason can be the appearance of the "dot jump" at the point (z) area, which obviously discontinued tonal smoothnesses of the reproduction (B) and (D).

No distinct difference was found between the reproduction (B) and (D) in tonal smoothness, even though some observers clearly noticed the difference. This

phenomenon was also proved by the circular triads,[2] which measure the consistency of the judgment.

When the smoothness of the reproduction (C) is examined, (C) did not receive enough pressure in middle tone and shadow areas, resulting in unprinted white spots, which caught the observers' eyes. As a result, the reproduction (A) has a better smoothness than (C). The same phenomenon can be seen when comparing (B) and (C), and (C) and (D).

When the reproduction (A) and (B), and (A) and (D) are examined, most of the observers chose the reproduction (A) rather than (B) or (D). The reason was the distingishable "dot jump" at the point (z) in the reproduction (B) and (D), which obviously discontinued the smoothness of the reproduced image.

It can be concluded that a normal duotone tone reproduction gives the best smoothness in this study when an adequate minimum pressure is applied; this is defined as the least pressure between the plate and the impression cylinder, which can consistently print a complete gray scale from the highlight to the shadow. Although the experimental duotone tone reproduction curve for flexography was proposed, the pressure does not visually affect the smoothness of a pictorial image as long as the pressure is minimum. Thus, the pressure affects the smoothness when a regular tone reproduction is applied. Solving the "dot

jump" problem is necessary if a experimental duotone tone reproduction is applied.

The Total Rendering Characteristics

The degree of defects were classified into:

* Major Defects ..... Smoothness of tonal rendering

* Minor Defects ..... Darkness range
  Highlight reproduction
  Shadow reproduction
  Consistency of reproduction

In this experiment, the visual judgment of a pleasing reproduction was avoided because of serious deficiencies in reproduced pictorial images. The judgment of the overall tonal redering in the reproduction was not the purpose of this experiment.

When the results of smoothness (C > B = D > A) are taken into the subject of pressure between the plate and the impression cylinder, it can be concluded that technique (1) which relates to (A) has a better smoothness than technique (2) which relates to (D).

The Print Quality Index (PQI) was calculated from the classified data (above) obtained in this experiment to judge the total tonal rendering characteristics.

PQI for Technique (1) = 10 - (5 * 0 + 2) = 8

PQI for Technique (2) = 10 - (5 * 1 + 2) = 3

The results indicated technique (1) has better total rendering characteristics than technique (2). Therefore, it is concluded that a normal duotone tone reproduction with the application of normal pressure gives a better image reproduction than the proposed experimental duotone tone reproduction with the application of different pressures.

ENDNOTES 6

1. "Manual on Sensory Testing Methods, ASTM Special Technical Publication 434." Philadelphia, PA. American Society for Testing and Materials. 1968 p64

2. Kendall, M. George. "Rank Correlation Methods". London, England. Charles Griffin & Company Limit. 1962 p146

CHAPTER VII

Conclusions and Recommendations

This thesis has investigated methods of minimizing the defect of plate height inconsistency, caused by plate elongation in the flexographic printing method. In this experiment, a duotone technique was used to improve the flexographic print quality. The hypothesis for this experiment was:

When a double-impression duotone is applied for flexography, the use of a different amount of pressure between the plate and the impression cylinder will result in improved Tonal Rendering Characteristics as compared to using equal pressure for both image carriers.

The results have indicated a normal duotone technique produces a better tonal rendering than the experimental duotone technique proposed in this study.

If tone reproduction characteristics were excluded from this experiment, the use of different pressures for each plate gave the best result. This was discussed in chapter 5. When a gray scale was reproduced, it was quantitatively proved that the relief-height tolerance causes decreasing print resolution. The relief height

difference was obvious in the gray scale. However, when a pictorial image was reproduced, the relief-height difference of the plate was not as clear as that of the gray scale. From this phenomenon, it seems that the relief-height difference of a complex scene is less than that of a simple gray patch because of the use of various dot sizes in an image area.

When the tone reproduction is taken into consideration, the dot jump problem is apparent. In this study, the starting point of the second impression for technique (2) was at the quarter tone area (approximately 25 percent film dot area), the other technique was at the middle tone area. (Figures on page 32) While no dot jump was observed in the middle tone area, dot jumps were clearly noticed in the quarter tone area, which interrupts the smoothness of tonal rendering. A digital scanner was used for this test. The scanner had a steep curve at the starting point, resulting in a drastic change of grayness. It is possible to minimize the dot jump if a tone reproduction curve for a scanner, which has a long toe, is designed.

This experiment assumed there was no defect in the plate height-difference except for the elongation of the plate. However, many defects do exist in actuality, which affects the plate height. As a result, the ability to control the pressure between the plate and the impression

cylinder by the pressmen, described in this thesis, is limited.

If the physics of a flexographic plate is considered, it can be stated that a thinner plate has less height tolerance than a thicker one because of the relative ratio of plate thickness. It is recommeded that thinner plate material be used for fine quality halftone reproduction. Further study should be done to improve the tonal rendering smoothness in highlight areas which is a significant problem in flexography. An investigation can be made using different solid ink densities for each impression to extend the tonal range with better highlight reproduction. This concept can be applied to the color process, using a large percentage of gray component replacement (GCR). It is recommended that a study of the relationship between plate height tolerance and the elongation of plates could be investigated by other researchers.

APPENDIX

Appendix A

Flexographic Plate Making Process

A-1 The process for molded rubber plates

1. Prepare a conventional negative
2. Put a UV-sensitive coating on the metal
3. Expose UV light to the dry plate coating through the negative, then the exposed coating is hardened and becomes insoluble in acid
4. Etch the unexposed part which is going to be non-image area
5. Mold a matrix board which is a phenolic thermosetting resin, from the metallic plate by applying heat and pressure
6. Squeeze rubber on the matrix at high temperature to duplicate the original image
7. Check the thickness and consistency of each molded rubber plate
8. If a plate has excess thickness, the back-side of the plate can be ground down.

A-2 Typical process for sheet photopolymer plate

1. Prepare the matte surface negative
2. Expose UV radiation to the photopolymer plate through the negative (pre-exposure is required for some types of photopolymer plate to activate monomer)
3. Wash the excess polymer in non-image area
4. Dry the plate
5. Finish the plate

Appendix B

Halftone Conversion Methods

Glass Cross Line Screen

Parallel lines were etched on two sheets of glass, which are then cemented together with the sets of lines at a right angle to create individual dot-forming openings. In order to get a halftone, the glass screen is placed at a predetermined critical distance from the film without contact. Since, it is very expensive and requires a high level of sophistication, few glass cross line screens are used today.

Contact Screen

It is a precision pattern of vignetted dots on a flexible support. It is used in direct contact with film or a plate, using a vacuum. The mechanism is described as:

> Light striking film through a contact screen must penetrate varying density in the form of a dot pattern on the screen in order to reach and expose the film. Intense light from highlight areas in the original penetrates even dense areas on the screen and exposes a large dot pattern on the film. The slight amount of light coming from dark areas, on the other hand, yields only small dots.

Chemco Co. adds that a contact screen today usually consists of a fine-grain emulsion on a high quality polyester-base film, protected by a special anti-Newton Ring coating. There are several kinds of contact screens available:

Gray ...... For all direct color separations and black-and-white halftone negatives. A gray screen has the characteristic of a short range of the density curve in highlight to middle tone.

Magenta ... This is a magenta-dyed contact screen which with the additional use of color correction filter controls the screen range available. A magenta screen has a long range of the density curve in highlight to middle tone.

Negative ... For making negative films

Positive ... For making positives

Single Dot ... Single ruling in a entire range, which is ordinary and most desirable pattern to print easily

Dual Dot ..... have a secondary ruling in the middle to shadow area in order to reproduce maximum detail, for low key subjects. Secondary dots tend to act as two separate screens.

Square Dot .... The dot shape is square which offers a

good conbination of tone reproduction and detail. The dot percentage is easy to determine.

Round Dot ..... The dot shape is rounded, used for high speed web offset to avoid plugging, trapping and dot gain in the low middle tone.

Elliptical Dot ... This screen has a diamond-shaped dot pattern which has a smoother tone rendition especially in the middle tones.

Elecronic Dot Generation

Each point of the orignal image is scanned and analyzed. This input data is digitalized to meet a computer and storage system. Then the data is sent to the output electronically which expresses the specific density of gray on the film. One feature of this system is the ability to correct data before output. Electronic dot generation is apllied in dot generation scanners and pagination systems.

Appendix C

Duotones

Two-Color Process

Although duotones are made in many places in the world, the term "duotones" is understood differently from shop to shop and area to area because of the many variations in color processes. Most of the articles mention some examples instead of describing how to make duotones because so many variables are involved. Eastman Kodak Co. stated in a technical bulletin that duotones were 95 percent art judgement and 5 percent technique. Professor Chung at Rochester Institute of Technology describes color duotones in TAGA Proceeding as the technique that the mixture of the two impressions for best visual results. The purposes of color process duotones are mainly:

1. To extend the density range.
2. To create an inexpensive two color reproduction.
3. To create artistic special effects.
4. To give more details.

Double-Impression (black)

The purpose of this duotone is defined:

1. To increase the maximum ink density to approximate the maximum density as the original.

2. To enhance shadow details.

Usually, the main printer is printed at 45 degree angle and the other is at plus or minus 30 degrees which is a 15 or 75 degree angle for lithography and letterpress.

The Process of Making Duotone by Process Camera

A few articles described the process of these reproduction curves. Eastman Kodak Co. explains the process:

> Curve A is obtained by the proper combination of main, flash, and highlight bump exposures. Curve B is usually made by using a long enough main exposure to put a small dot in the deepest shadow without the help of a flash exposure. The main printer (curve A) will give good highlight and middle tone contrast, while the other printer (curve B) will add good shadow contrast or detail, and the total ink density in the shadows from the two impressions will give the higher maximum density which will closely match the high shadow density in the glossy original.

Appendix D

Additivity Failure of Flexographic Ink

First-surface Reflection

When light strikes a paper or ink surface, about 4% of the light is reflected at the surface without changing any surface conditions. The ratio of excess reflection is caused by the variations of surface gloss, such as gloss and matte-surface.

Multiple Internal Reflection

The reflection density is not propotional to the transmission density of the ink film. As the light penetrates the ink, the ink particles cause multiple internal reflections. The rate of penetration depends on the thickness of the ink.

Ink Opacity

The opacity is defined as the reciprocal of the transmittance due to the scattering of light caused by differences in the reflective index between the pigment and the vehicle. The reflection is different with the types of inks, opaque or transparent. Ideally, opaque inks allow light to reflect or absorb into the ink layer. Transparent ink absorbes a certain portion of light, and penetrates others, rather than reflects. An opaque ink always gives a

lower reflection density than it would if it were transparent but had the same light-absorbing power.

Trapping

When ink is transferred to paper, the layer of ink on the printing plate is divided between the two surface. Since the nature of the surfaces between a previously printed ink layar and a plain paper are diferent, the proportion and the uniformity of transferring ink are different. This behavior will affect the additivity of densities, but quantitative predictious are difficult to make.

Halftone Structure

The additivity behavior of halftone tints is theoretically different from that of continuous tone which has a solid ink structure. Since the nature of ink and paper and a limitation of the press precise control, it is difficult to get accurate results. A special care must be taken to minimize errors.

Appendix E

The Data and Results of the VARIANCE RATIO TEST

Technique 1			Technique 2		
Highlight	Midtone	Shadow	Highlight	Midtone	Shadow
.20	.79	1.72	.19	.98	1.54
.19	.87	1.72	.20	.86	1.53
.20	.86	1.73	.17	.91	1.54
.21	.90	1.73	.17	.83	1.55
.21	.79	1.76	.17	1.01	1.55
.20	.64	1.74	.18	.91	1.56
.18	.65	1.74	.16	1.00	1.55
.20	.63	1.75	.16	.81	1.50
.20	.72	1.74	.18	.88	1.56
.20	.61	1.76	.18	.95	1.58
.20	.69	1.72	.21	.91	1.55
.20	.74	1.74	.18	.93	1.61
.21	.72	1.78	.17	.89	1.52
.21	.80	1.71	.18	.90	1.58
.21	.76	1.75	.19	.94	1.53
.19	.78	1.71	.19	.97	1.57
.19	.70	1.73	.18	.90	1.56
.20	.67	1.72	.19	.99	1.53
.21	.69	1.79	.18	.91	1.54
.20	.67	1.75	.19	.94	1.55
.21	.93	1.75	.19	.93	1.55
.20	.67	1.69	.17	.78	1.54
.19	.68	1.73	.19	.82	1.53
.20	.63	1.70	.19	.89	1.53
.21	.66	1.73	.17	.91	1.53
.20	.74	1.71	.18	.77	1.50
.20	.70	1.74	.17	.81	1.47
.20	.77	1.70	.17	.89	1.51
.20	.71	1.76	.18	.90	1.53
.20	.81	1.73	.17	.81	1.48
.20	.71	1.70	.17	.88	1.50
.20	.80	1.74	.17	.88	1.52

Appendix F

The Data and Results of A PAIRED COMPARISON TEST

--- DATA (Chapital letter is prefered by observers) ------

1.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

2.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

3.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

4.(A)-(b), (A)-(c), (A)-(d), (b)-(C), (b)-(D), (c)-(D)

5.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

6.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (C)-(d)

7.(A)-(b), (A)-(c), (a)-(D), (B)-(c), (B)-(d), (c)-(D)

8.(A)-(b), (A)-(c), (a)-(D), (b)-(C), (b)-(D), (C)-(d)

9.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

10.(a)-(B), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

11.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

12.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

13.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

14.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

15.(A)-(b), (A)-(c), (A)-(d), (b)-(C), (B)-(d), (C)-(d)

16.(a)-(B), (A)-(c), (A)-(d), (B)-(c), (B)-(d), (c)-(D)

17.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

18.(A)-(b), (A)-(c), (a)-(D), (B)-(c), (b)-(D), (c)-(D)

19.(A)-(b), (A)-(c), (A)-(d), (B)-(c), (b)-(D), (c)-(D)

20.(A)-(b), (A)-(c), (a)-(D), (b)-(C), (b)-(D), (c)-(D)

21.(A)-(b), (A)-(c), (a)-(D), (B)-(c), (b)-(D), (c)-(D)

22.(A)-(b),	(A)-(c),	(a)-(D),	(B)-(c),	(B)-(d),	(c)-(D)
23.(A)-(b),	(A)-(c),	(A)-(d),	(b)-(C),	(B)-(d),	(c)-(D)
24.(A)-(b),	(a)-(C),	(a)-(D),	(b)-(C),	(B)-(d),	(C)-(d)
25.(a)-(B),	(A)-(c),	(A)-(d),	(B)-(c),	(B)-(d),	(c)-(D)
26.(A)-(b),	(A)-(c),	(A)-(d),	(B)-(c),	(B)-(d),	(c)-(D)
27.(A)-(b),	(A)-(c),	(a)-(D),	(B)-(c),	(b)-(D),	(c)-(D)
28.(a)-(B),	(A)-(c),	(A)-(d),	(B)-(c),	(B)-(d),	(c)-(D)
29.(A)-(b),	(A)-(c),	(A)-(d),	(b)-(C),	(B)-(d),	(c)-(D)
30.(A)-(b),	(A)-(c),	(A)-(d),	(B)-(c),	(B)-(d),	(c)-(D)
T. 26-04,	29-01,	22-08,	23-07,	18-12,	04-26

The critical number at 95% significant level .... 21 / 30

Circular Traids Test

	A	B	C	D	TOTAL	X^2
A	---					
B		---				
C			---			
D				---		

$$SUM(X^2) = \sum^{n} ai^2$$

$$d = \frac{1}{12} n(n-1)(2n-1) - \frac{1}{2} \sum ai$$

$$= 1 - \frac{24d}{n^3-4n}$$

Appendix G

Duotone Chart Data Sheet

Technique 1

	2nd	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	91	1.57	1.54	1.55	1.41	1.62	1.60	1.73	1.75	1.84	1.89	2.02	2.03	2.09	2.09	2.16
14	80		1.41	1.27	1.42	1.45	1.56	1.59	1.63	1.72	1.86	1.89	1.90	2.13	2.00	2.03
13	72	1.08	1.20	1.19	1.18	1.28	1.38	1.55	1.54	1.66	1.79	1.81	1.79	1.91	2.00	1.96
12	67		1.09	1.03	1.15	1.16	1.28	1.41	1.59	1.64	1.66	1.68	1.80	1.82	1.90	1.89
11	61	.92	.99	1.04	1.08	1.11	1.31	1.31	1.54	1.48	1.60	1.73	1.67	1.77	1.84	1.82
10	44		.84	.88	.88	.95	1.10	1.16	1.33	1.36	1.46	1.45	1.56	1.63	1.74	1.77
9	37	.69	.80	.76	.78	.99	.96	.99	1.23	1.20	1.44	1.44	1.53	1.46	1.66	1.70
8	28		.62	.61	.66	.78	.80	.98	1.20	1.14	1.28	1.27	1.35	1.41	1.58	1.69
7	21	.38	.49	.60	.60	.69	.73	.86	1.00	1.04	1.16	1.33	1.21	1.38	1.60	1.65
6	15		.44	.45	.52	.47	.62	.72	.87	.93	1.06	1.23	1.30	1.41	1.63	1.64
5	9	.21	.30	.35	.43	.43	.58	.65	.76	.83	.89	1.08	1.28	1.28	1.52	1.61
4	5		.23	.27	.33	.40	.48	.63	.75	.83	.95	1.06	1.20	1.29	1.49	1.54
3	3	.13	.21	.24	.29	.35	.46	.56	.68	.78	.88	.99	1.17	1.30	1.48	1.54
2	1		.14	.15	.20	.28	.43	.55	.74	.82	1.03	1.00	1.24	1.38	1.50	1.50
1	0	0	.08	.09	.16	.22	.30	.38	.58	.74	.98	1.00	1.10	1.19	1.47	1.50
2nd / 1st		1	2	3	6	10	16	22	29	36	52	58	64	72	80	92

	98	96	94	92	Solid	8	6	4	2	25	50
Plate #1					1.72						
Plate #2					1.59						

Duotone Chart Data Sheet

Technique 2

	2nd	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15																
14																
13																
12																
11																
10																
9																
8																
7	21	.32	.39	.41	.47	.50	.65	.72	.94	.94	1.00	1.10	1.09	1.48	1.50	1.71
6	15	.27	.37	.40	.49	.50	.64	.77	.81	.89	.89	1.13	1.24	1.38	1.55	1.60
5	9	.21	.28	.31	.40	.44	.54	.61	.71	.89	.97	1.12	1.25	1.29	1.51	1.54
4	5	.15	.23	.25	.34	.38	.45	.50	.65	.80	.92	1.04	1.23	1.30	1.50	1.52
3	3	.13	.19	.19	.25	.32	.38	.50	.63	.78	.94	.97	1.02	1.25	1.35	1.48
2	1	.04	.12	.13	.20	.24	.34	.43	.57	.72	.85	.89	1.09	1.20	1.42	1.48
1	0	0	.08	.08	.15	.21	.32	.40	.51	.65	.82	.83	.94	1.18	1.35	1.41
1st		1	2	3	6	10	16	22	29	36	52	58	64	72	80	92

	98	96	94	92	Solid	8	6	4	2	25	50
Plate #1					1.71						
Plate #2											

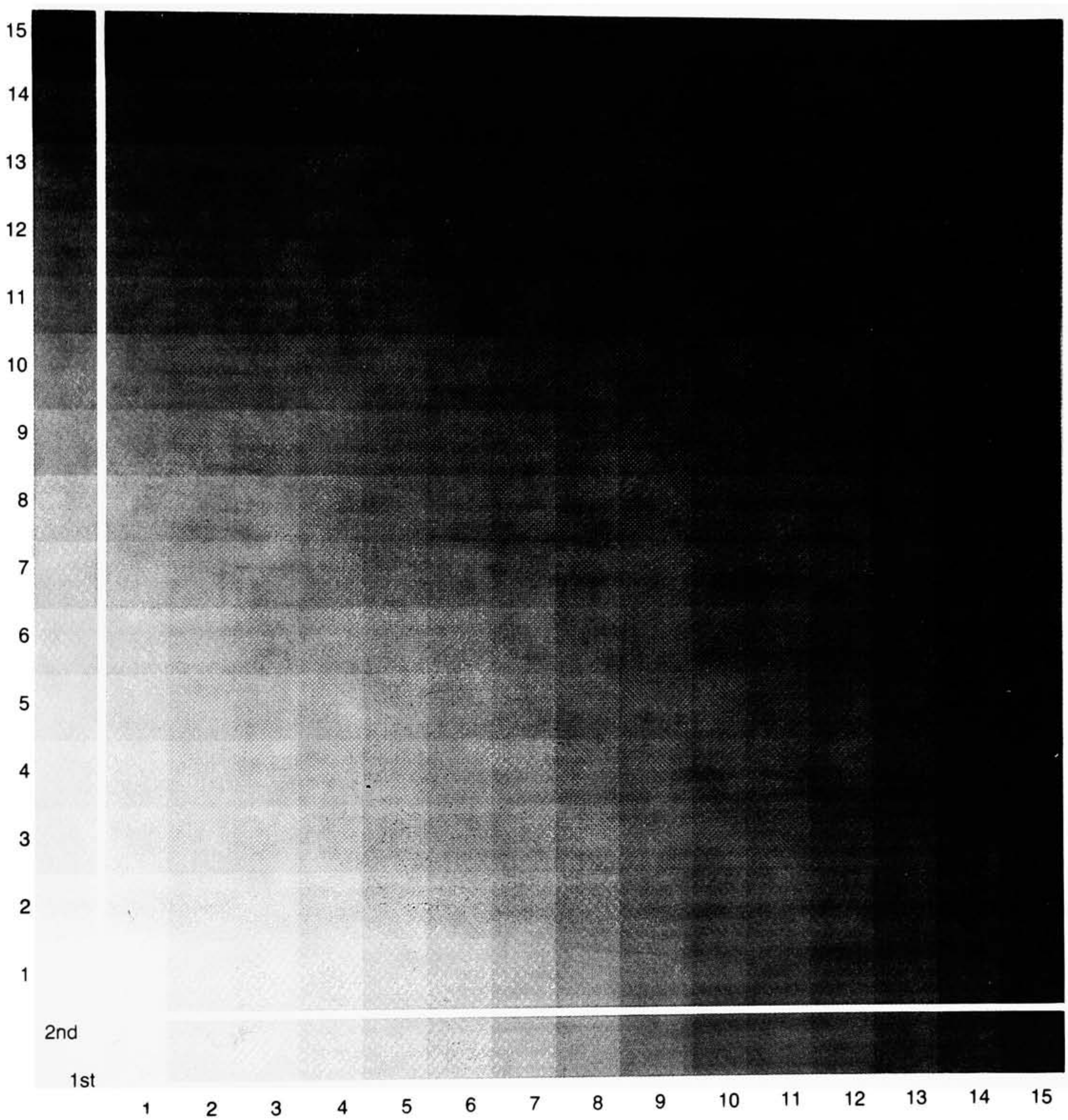


Figure 16. The Press Sheet Sample for Technique 1

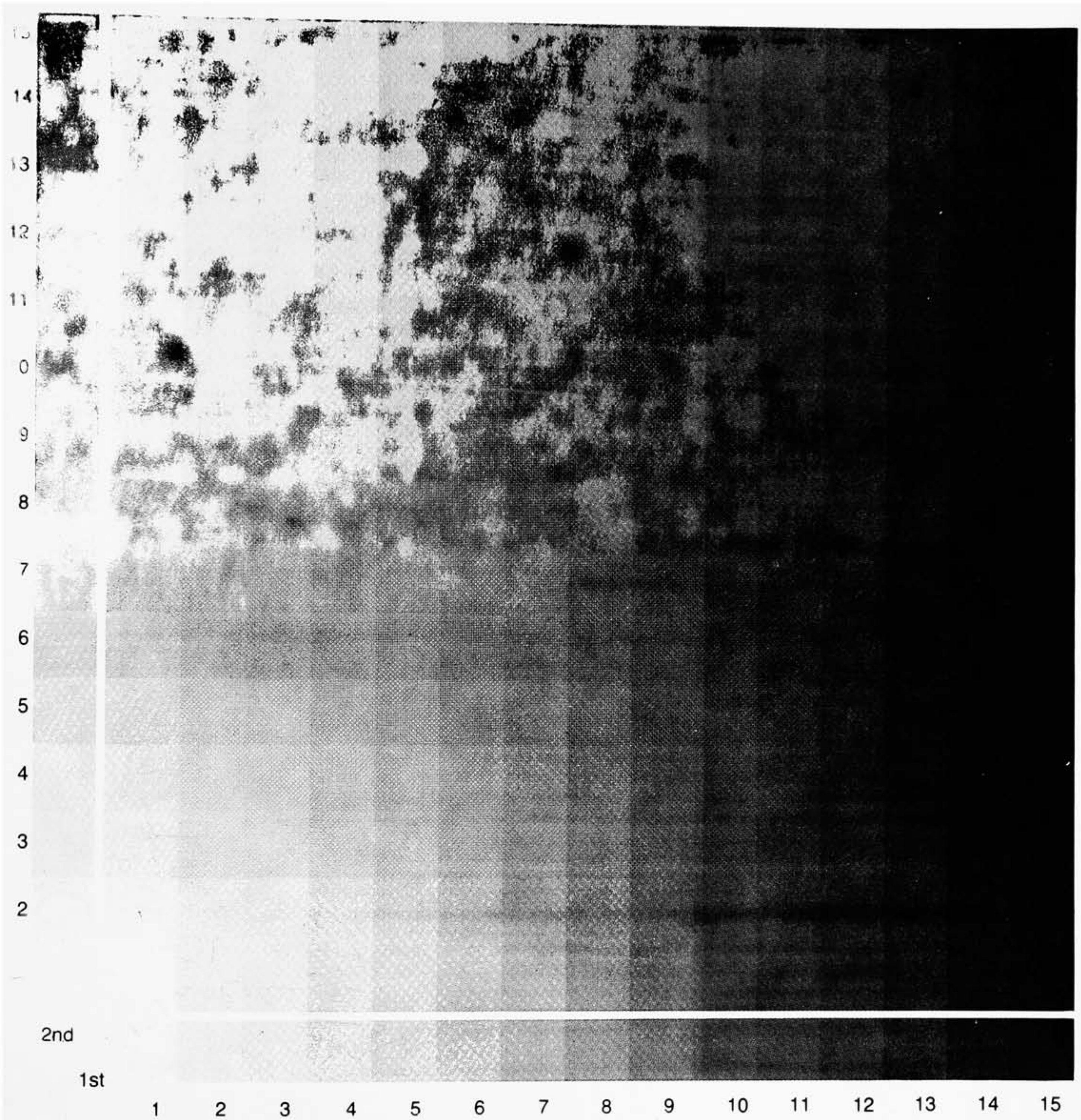


Figure 17. The Press Sheet Sample for Technique 2

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