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A study of the effect on direct stencil edge definition of emulsion thickness, screen mesh count, fabric thread thickness and coater blade thickness

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A STUDY OF THE EFFECT ON DIRECT STENCIL EDGE DEFINITION OF EMULSION THICKNESS, SCREEN MESH COUNT, FABRIC THREAD THICKNESS AND COATER BLADE THICKNESS

by

George Bedirian

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
School of Printing in the College of Graphic Arts and Photography
of the Rochester Institute of Technology

May, 1977

Thesis adviser: Professor Robert J. Webster

Certificate of Approval--Master's Thesis

School of Printing
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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

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with a major in printing education
has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of

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Thesis adviser

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My thanks to Professor Robert J. Webster, whose enthusiasm and friendship led me down the path of discovery in printing, and whose encouragement has borne fruit in this paper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A STUDY OF THE EFFECT ON DIRECT STENCIL EDGE DEFINITION OF EMULSION THICKNESS, SCREEN MESH COUNT, FABRIC THREAD THICKNESS AND COATER BLADE THICKNESS

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An Abstract

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The present study arose out of a desire to test the assumption that in order to obtain direct stencils with good edge definition, one either had to use fine screens or, if using a relatively coarse screen, apply multiple coatings of emulsion to the screen before making the stencil. Neither alternative seemed satisfactory, since the first did not allow optimal use of the scope of screens available, and the second entailed an expenditure of time and supplies that could possibly be shown to be unnecessary.

It was therefore determined to carry on an experiment that would show whether direct stencils with good edge definition can be obtained on relatively coarse screens with only one, or at most two applications of emulsion. The experiment thus envisioned also provided an opportunity to observe the influence on two other factors on stencil edge definition, besides those of mesh count and emulsion thickness: namely, screen thread diameter and coater blade thickness.

What finally evolved was a three-factor, three-levelled factorial experiment, in which the variables under study were screen mesh count, thread diameter and emulsion thickness. The fourth factor came into play when the experiment was run once for emulsions applied with a thick-bladed coater, and once for those applied with a thin-bladed coater. The specific question under study was: in the direct stencil system, is there a difference in the quality of edge definition obtainable with variations in screen mesh count,

screen thread diameter, coater blade thickness and the number of emulsion coatings applied?

Eighteen screens were stretched expressly for the experiment, representing three different mesh counts and three different thread diameters for each mesh count. Each screen was prepared in such a way as to receive three stencils of varying thickness per screen. All stencils were exposed to a test target designed to allow for the observation of diagonal and parallel stencil edges (i.e., diagonal or parallel with relation to screen thread direction). After the stencils were made, they were visually inspected, and the data obtained thereby was subjected to an analysis of variance.

The results obtained showed that of the four factors studied, mesh count was the only one that made a clear difference in the quality of stencil edge definition. What the experiment did not conclusively show was whether or not coater blade thickness had any influence on that quality.

Nevertheless, what is perhaps of greater significance to the printer in industry is that the experiment did show that on a coarse screen a stencil with good parallel edge definition could be obtained with only one coating of emulsion (as one coating was defined in the experiment).
Abstract approved:

CHAPTER I

INTRODUCTION

Screen printing is in the midst of a technological explosion which is rapidly transforming it from primarily a craft discipline to a mechanized, scientific industry. Already in large segments of the field this transformation has been effected. Over the past several decades improvements in the areas of fabrics and stencil materials, among others, have made possible the reproduction of the kind of fine detail that was thought to be the province of gravure and offset alone. And these developments have brought it within the range of screen printing to produce consistent, repeatable work of the highest quality.

The modern screen printer, then, has available to him three major types of fabrics. There are nylon fabrics which, because of their elasticity, enable him to print on contoured surfaces without causing the screen to wear prematurely; polyester fabrics, which resist moisture and are therefore dimensionally stable, insuring good register in multicolor work; wire fabrics, which permit the reproduction of the finest detail and the most exacting close-tolerance work; and most recently, metalized polyester, which combines the capabilities of wire mesh with the flexibility of the synthetics. Moreover, all of these fabrics are available in a wide variety of mesh grades, from very coarse to very fine, the relative coarseness or fineness of the material--its <u>mesh count</u>--depending upon the number of threads per linear inch (or centimeter) it contains. A 170 polyester fabric, for example, would be known to have 170 threads per inch, if the measure were in inches; if the measure were in centimeters, however, the same fabric would be designated as a 66. Whatever the system of measurement used, the number attached to the fabric immediately identifies it in terms of its relative fineness.

Combined with variations in mesh count is the range of thread thicknesses in which the synthetics, especially nylon, are available. Where such a range exists, a fabric of a given mesh count will have at least medium and heavy-duty thread thicknesses; and in the case of nylon, fine, medium and heavy-duty thicknesses. These are designated S, T and HD respectively. (Some come in an M grade, intermediate between S and T, but for the purposes of this study only the S, T and HD need be considered). The presence of such a wide range of choice as between fabric materials, mesh counts and thread thicknesses allows the screen printer not only to select just the right screen for a particular job, but also allows him to exert control, through fabric selection, of the printing process in terms of ink film deposit, drying time and, ultimately, of quality.

As it is with fabrics, so it is with stencils. Over the years three distinct stencil systems have developed, each with its uses and unique capabilities: the indirect, direct-indirect and direct systems. Although this study is concerned exclusively with the direct system, it would be well to describe briefly the other two systems in order to place the direct in perspective.

In the indirect system the image is formed on a film that is either sensitized just prior to exposure, or that is supplied in presensitized form. The exposure is made with actinic light through a photographic or mechanical positive. The exposed portion of the film undergoes a chemical change, which with hardening will render it insoluble in water. The unexposed portion, on the other hand, remains soluble. After exposure, the film is "developed" in a hardening solution, and the unexposed portions of the emulsion are washed out with a fine spray of water. It is only at this point that the film is adhered to the screen, becoming thereby a stencil.

Because in the indirect system image formation occurs before the film is attached to the screen, the quality of that image is not dependent on the characteristics of the screen, such as thread composition, thickness and color. Whatever variations may occur within the fabric, the quality of the stencil image, if properly made, will be of a high order. However, it is this very freedom from interference by the screen, which accounts for the system's weakness. Since the film is not an integral part of the screen at the outset, it is prone to separation from the screen at any point after adhering, and for this reason is practical only for short-run work. Nevertheless, when used properly, it is an excellent method of stencil formation.

The direct-indirect stencil--also known as the transfer stencil and the film-emulsion stencil--is far more durable than the indirect, and also shares some of its ability to render sharp images. It is made by placing the screen, underside (or job side) down, on a piece of film consisting of an unsensitized emulsion and a base of either paper or plastic. A layer of sensitized emulsion is then squeegeed or brushed onto the film through the squeegee side of the screen. This not only encapsulates the screen within a coating of emulsion, but also serves to bind the emulsion of the film to the screen and to the sensitized emulsion. After the screen is dry, the base of the film is stripped off, leaving a smooth, even coating of emulsion on the job side. The screen is exposed to actinic light, the same hardening action occurring in the emulsion as took place in the indirect film. Immediately after exposure the stencil is washed out with water, the image forming by the dissolution of unhardened areas of emulsion.

Because the emulsion and screen are made into a unit before exposure, the direct-indirect stencil is more dependent on the screen fabric for image quality than the indirect stencil, but less so than the direct. For example, if too coarse a screen is used, wherever an image edge on the stencil runs diagonally to the direction of the fabric threads, it will be rendered as a serrated, or sawtoothed, pattern rather than as a straight line. Nevertheless, this effect will be minimized because of the smooth layer of emulsion that is left on the job side after the film base is stripped away. All of this notwithstanding, the great advantage of this system is its capacity to withstand much more wear than the indirect stencil, while retaining much of the image quality of the latter.

Unlike the foregoing systems, the direct entirely precludes the use of any sort of film. Rather, it consists solely of an emulsion that is applied to the screen in liquid form, either with a brush, a piece of cardboard, a squeegee, or most appropriately a metal doctor blade, with or without a reservoir attached. The earliest type of direct emulsion, first used around 1912-14.[1] consisted of a mixture of glue and gelatin applied to the screen with a brush and, when dried, sensitized with a mixture of gelatin, glue and ammonium bichromate.[2] From that time until practically our own day the colloids used in direct stencils consisted of either gelatin, glue, albumen or variations thereof, sensitized after application with bichromated compounds. Because of the nature of the colloids used, the emulsions had to be heated before being applied; and because of the instability of the bichromates the stencils had to be exposed very quickly after they were sensitized.

It was not until the past few years that two significant advances occurred. The first was the development of polyvinyl alcohol (PVA) and polyvinyl acetate (PVAC) emulsions which require no heating before use and which can be stored for extended periods. The second was the substitution of diazo sensitizers for the bichromates, which, though not complete, is rapidly gaining ground, Because diazo is a stable substance, undergoing no dark reaction as the bichromates do, it can be used to presensitize the synthetic colloids, making their use much simpler and more convenient than the old gelatin and glue types of direct stencil. For the same reason, emulsions made with diazo-sensitized synthetic colloids need not be exposed immediately after application. This means that large numbers of screens can be pre-coated, stored and used as needed, a procedure that is much more efficient for the large-volume printer than that of coating each screen as it is needed.

As the materials that compose the direct stencil have undergone sophistication, so have the techniques of applying it. If the brushes and pieces of cardboard that were heretofore used are not entirely gone, they are being replaced by more rational alternatives.[3] The modern screen printer uses a metal coater, either a flat blade called a scrape coater, or a similar device with a reservoir attached for holding a large quantity of emulsion, called a scoop coater. Holding the screen vertically, the printer applies a coating of emulsion to the job side of the screen, running the blade along the screen from bottom to top. If he desires to coat the job side a second time, he turns the screen 180 degrees and repeats the coating action, again from bottom to top. He then turns the screen over and repeats the above procedure on the squeegee side, applying two coats as before. This sequence of coating steps insures that the layer of emulsion will eventuate on the job side.

After coating the screen, the printer dries it in a horizontal position, job or emulsion side down, placing the frame on blocks to prevent the wet emulsion from touching the drying surface. If he chooses to expose the stencil immediately after drying, he does so in the same way that he would expose a direct-indirect stencil, and he subsequently washes out the exposed stencil, leaving the image areas open for the passage of ink.

FOOTNOTES TO CHAPTER I

1. E.J. Kyle, "Modern Photostencil Methods, Part 6," Screen Printing (September, 1974), 36.

2. Albert Kosloff, "The Basics, Part Seven," Screen Printing (November, 1972), 32.

3. See Clair Donovan, Speech, Proceedings of the 20th Annual Conference, May 6-7, 1975, Research and Engineering Council of the Graphic Arts Industry, p. 55.

CHAPTER II

STATEMENT OF THE PROBLEM

Combined with its simplicity of preparation are a number of other factors which have made the direct the leading choice of stencils among commercial screen printers. Among these are its relative cheapness and its almost legendary durability, which enables it to withstand long runs and repeated washups. These are qualities which would appear, under the right conditions, to make the direct the ideal stencil system. Nevertheless, the direct system is not without its difficulties. Under certain circumstances it will yield images with poor edge definition, *i.e.*, images with ragged, or in some instances, sawtoothed edges. To a certain extent this effect is caused by the scattering of light along the screen threads during the exposure of the stencil. This was recognized quite soon after such stencils came into use, and colored screens--yellow, orange and red--were developed to minimize light scattering and the consequent undercutting which caused poor edge definition. In some cases the dyed fabrics improved stencil resolution. But in other instances, particularly those in which the emulsion had been applied to relatively coarse screens, poor edge definition persisted. It was quickly recognized that the cause of this category of bad edge definition lay chiefly in the characteristics of the emulsion itself, which, when applied too thinly to a relatively coarse screen, had a tendency to pull in toward the edges of the screen threads while drying, and to form images that conformed more to the shape of the screen than to the image the emulsion was supposed to reproduce. In other words, the emulsion at the image edge bridged the open areas between the screen threads not in a straight line, but in a concave pattern, or failed to bridge the open areas altogether, following a general outline of the image edge along the screen threads in a stepped pattern that was an approximation, but not a duplication, of the desired edge.

What was needed, obviously, was some means of supporting the emulsion where it bridged these relatively large screen openings. Two methods evolved, which today remain the standard remedies for poor edge definition: 1) the application of multiple coatings of emulsion with intermediate drying, thereby building a thick enough layer for support at the image edges, and 2) the use of a finer screen, which requires the emulsion to bridge smaller open spaces at the image edge. As expedient measures both solutions are satisfactory. Multiple coating does, in fact, greatly improve edge definition, eliminating both the raggedness and sawtoothing effects mentioned above. (It might be noted, by the way, that no firm standard has been set as to what constitutes multiple coating; however, a typical example would probably be one coating on the squeegee side of the screen and up to four coatings, with intermediate drying, on the job side.) The substitution of a finer screen for a coarser one, while it does not totally eliminate poor edge definition, reduces it to the extent that it becomes less noticeable, the degree of reduction depending upon the fineness of the alternate screen. It must be understood, of course, that fineness of screen in this connection is a relative concept. Nevertheless, it has been suggested that in screens with a mesh count of 260 or higher bad edge definition becomes so slight as to be negligible.[1]

To repeat, these solutions are quite satisfactory as expedient measures. However, each entails difficulties of its own. Since multiple coating involves the necessity of waiting for each successive coating to dry before a new one can be applied, it is both time-consuming and costly. And for certain jobs a fine-mesh screen might be totally inappropriate, as when a thick film of ink is desired. To be sure, the application of additional coatings of emulsion to a fine-mesh screen will increase the thickness of the printed ink film. But this only takes us back to the difficulty involved in multiple coating. If, as screen printers are told, the wide range of mesh counts in which screen fabrics are available makes it possible for them to choose the right fabric for the job at hand, then they should not have to compromise that choice by going to a finer fabric because of a problem with edge definition.

What is clearly needed is more research into the area of fabric-emulsion relationships to determine if there is some way, besides those recommended, of achieving good edge definition with direct emulsions. Most, if not all, of the research in the area of fabric-emulsion-ink film relationships has been done by the fabric manufacturers themselves. While their research has been extensive, it has not been exhaustive. A number of variables have thus far been ignored, most notably screen thread thickness as it effects the behavior of emulsions after they have been applied, and the thickness of the applicator blade itself. It is only fair to say that these companies have studied the relationship of screen thread diameter to ink film thickness and print quality; but in their published manuals there is no evidence that they have addressed themselves to the effect of thread diameter on the bridging characteristics of direct emulsions.

It was pointed out in the Introduction that most synthetic screen fabrics are available in a wide variety of mesh grades and thread thicknesses. For screens of any given mesh count, differences in thread thickness entail differences in open mesh size, so that as far as open area is concerned, an HD variant will bear the same relationship to an S fabric as a fine fabric will to a coarse. There fore, since it is already known that the bridging characteristics of direct emulsions improve with increasingly fine fabrics, it seems reasonable to expect that edge definition will be better in a T variant than in an S, and better still in an HD than in a T. At least this is a matter worth investigating.

As mentioned above, the other factor which screen researchers have ignored is that of the thickness of the coater blade with which the emulsion is applied. The two types of metal coater, scrape and scoop, have already been described. A number of factors determine how thick a coating of emulsion will be applied to the screen with each pass of the coater--e.g., pressure and blade conformation--but everything else being equal, the thicker the gauge of the blade, the thicker the coating of emulsion will be. Again, there are implications for edge definition here. We already know that a thicker emulsion coating improves the mesh-bridging characteristics of the stencil at the image edge. It would no doubt be of benefit if we could apply such a coating with one pass, using a thick-bladed coater, rather than with two or more passes. This too seems worth investigating.

These are the factors, then, that ought to be studied in an investigation of edge definition in direct stencils: not only mesh count and emulsion thickness, as has hitherto been done, but also screen thread diameter and coater blade thickness. If an optimal relationship exists between these factors, such that good edge definition can be obtained without either multiple coating or the use of fine screens, then in those situations where good edge definition is deemed essential, the benefits of efficiency and economy will accrue to the printer. The awareness of such a relationship could result in the elimination of the extra time and labor expended in multiple coating, and in the saving of money spent on the more expensive finer screens.

The particular question under investigation, is this: in the direct stencil system, is there a difference in the quality of edge definition obtainable with variations in screen mesh count, screen thread diameter, coater blade thickness and the number of emulsion coatings applied?

FOOTNOTES TO CHAPTER II

1. *Manual for the Use of Nytex Nylon Monofilament Screen Fabrics for the Graphic Arts Industry* (Zurich: Zurich Bolting Cloth Mfg. Co. Ltd.), p. 29.

CHAPTER III

RELATED RESEARCH

Compared to the volume of research being carried on in lithography today, the amount being done in screen printing is practically negligible. Perhaps this is only to be expected, considering the relative importance of the two processes. Nevertheless, there is a certain amount of research under way in screen printing--not by any independent groups such as GARC and GATF--but almost wholly by manufacturers and suppliers, and in very rare cases by individuals. It is probably because of this situation that so little printed information is available regarding the character of this research, and that no one really knows just how much of it is being done. Certain indicators are available, however, mainly in the products, pronouncements and publications of suppliers. For example, the fact that the Advance Process Supply Company offers to its customers a stencil making service, using a proprietary emulsion called the Photosonic Screen, which is supposed to be a superior type of direct emulsion, obviously implies that a research effort led to its development. In another example, Clair M. Donovan, president of General Research Company, mentioned in a recent talk that his company, which manufactures and markets screen printing presses, devotes between 12 and 16% of its budget to research.[1] In the same talk he alluded to research going on elsewhere in the areas of ink drying, emulsion coating application, precoated fabrics and fine mesh fabrics.[2]

By far the most impressive indication of the depth of research being done is offered by the technical manuals published by the Swiss Silk Bolting Cloth Manufacturing Company, the Zurich Bolting Cloth Manufacturing Company and the Saati Group, an Italian organization. Including sections on screen frames, fabric stretching, mesh characteristics, screen preparation, ink film thickness, stencil systems, half tone printing and other subjects, they stand like the proverbial tip of the iceberg, only suggesting the enormous volume of work that must have gone into their production, but actually revealing very little of it.

Only two examples of individualized, small-scale research are available, and they are quite open-handed about the methods of investigation employed. The first is reported in the September, October and November, 1974, editions of Der Siebdruck, and involves a study by W. Heidsiek and A. Hopp of the relationship between half-tone rulings, fabrics and substrates, and contains a detailed account of the procedures and results of the study.[3] As an example of independent research it is invaluable; but as it has little relationship to the present study, it need be discussed no further here.

More germane to the purposes of this paper is an investigation made by E. J. Kyle of the resolution capabilities of the direct-indirect stencil, reported in a series of six articles that appeared in Screen Printing between November, 1970, and June, 1971. The title of the series, "Toward the One-Mil Line,"[5] is significant, in that it indicates the nature of the investigation it reports, the purpose of which was not to print a one-mil line, but to arrive at a procedure whereby one could test one's ability to do so.

Basically, what Kyle did was expose a number of direct-indirect stencils to a test object and evaluate them, both by measurement and by photomicrographic study. In the absence of a suitable pre-existing test object, he designed one himself. The object that finally evolved (Figure 1) consisted of "a quarter-circle of seven (concentric) zones, marked in alphabetical order from outer zone A to inner zone G."[4] Each zone consisted of a series of "image units," rows of straight lines arranged in clusters of three. The zones were arranged so that the lines radiated in 15-degree steps, from zero to 90 degrees. Each image unit was labelled numerically and alphabetically, and each cluster was labelled with its degree orientation. Thus, if one were examining a stencil made from the target, one would know from these markings precisely what portion of the target he was observing.

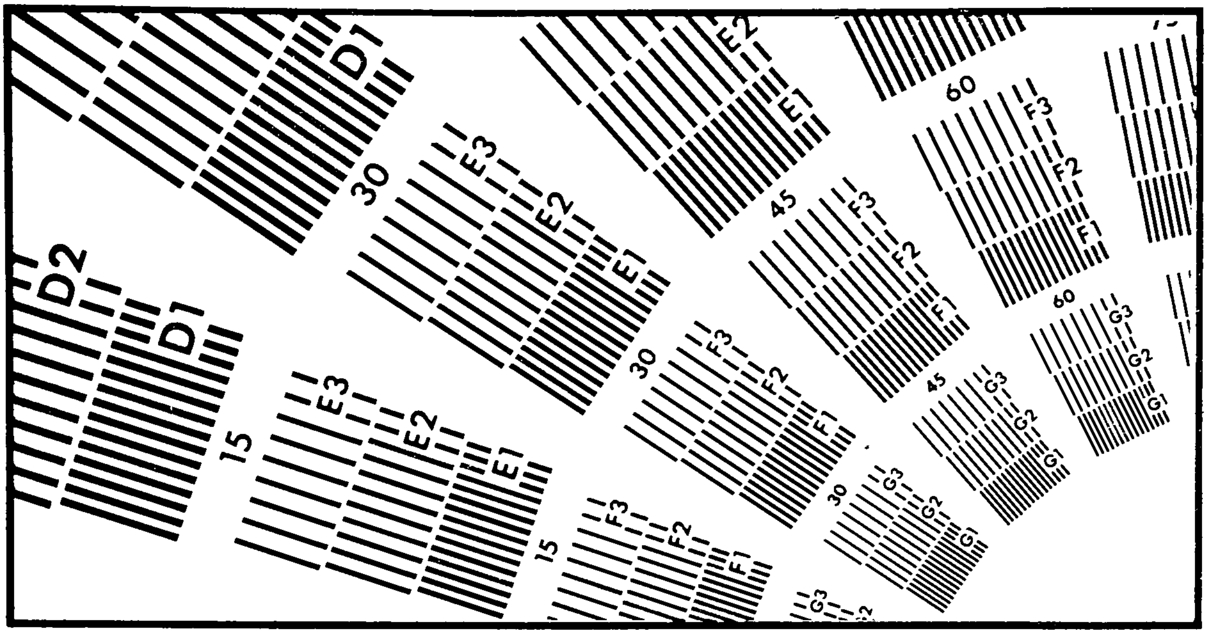

Figure 1

A portion of E.J. Kyle's test object[5]

It is this target, rather than the use Kyle made of it, that is of interest here. For this reason, no more need be said about Kyle's investigation, except that, as will be seen, the test object used in the investigation reported in the present paper will be modelled after the one Kyle designed.

FOOTNOTES TO CHAPTER III

1. Donovan, p. 47.

2. pp. 54, 55.

3. "Untersuchung uber die Beziehungen zwischen Siebdruckgeweben, Rasetrgeweben und Drucktragen," XX.

4. June, p. 21.

5. *Ibid.*, p. 20.

CHAPTER IV

THEORETICAL BASES

It is well established that with direct emulsions edge definition is a function of, among other things, the combined factors of emulsion thickness and screen mesh count. To discuss any of these or any other single factor that might be involved apart from the others, therefore, is somewhat of an artificial procedure, but necessary for purposes of analysis. With this stipulation in mind, the theoretical justifications for studying the variables of emulsion thickness, mesh count, thread thickness and coater blade thickness are here given.

Emulsion Thickness

When a liquid emulsion is applied across a mesh surface such as a printing screen, it is required to cover not only the threads that make up the screen, but also the openings between those threads. It is here in these open areas that the emulsion obeys the physical laws of surface tension, pulling away from the center of each opening and toward the edges of the screen threads, leaving a relatively thin layer of emulsion in the open mesh.[1] If after drying such a layer of emulsion were observed in cross-section, it would be seen to possess a distinctly concave shape on its top and bottom surfaces, the thinnest point occurring in the center of the open area of the mesh, and the thickest coinciding with the intersection of two strands of fabric. Consequently, wherever an image edge in the processed stencil were to cross a mesh opening, it would have, when viewed from above, a similarly concave shape. Although this effect obtains in screens of all mesh counts, in screens of 260 mesh or higher the concave pattern becomes so fine-grained as to be unnoticeable under ordinary viewing conditions. In the coating procedure, however, as additional layers of emulsion are added to the original coating, the concave "valleys" in the mesh openings become filled; and because the emulsion's ability to bridge the open areas is thereby increased, edge definition improves.

Mesh Count and Thread Thickness

As implied above, screens of progressively finer mesh counts evince to a lesser and lesser degree the faulty edge definition that results from emulsion concavity in open mesh areas. Now if one were to compare three screens of the same mesh count, but of varying thread thicknesses, one would discern a marked difference in the size of the mesh openings of each screen. For although the number of these openings would remain the same for all three screens, the increasing thread thickness of the T and HD varieties would necessitate a progressive reduction in the mesh size. This may or may not have theoretical implications for the bridging characteristics of direct emulsions. If in the case, say, of a 170S screen, a single coating of emulsion results in bad edge definition because of improper bridging, a similar single coating might successfully bridge the smaller mesh opening of a 170 HD screen. On the other hand, the increasing thread thicknesses of the screens from S to HD might create an increasing degree of concavity due to the accentuation of the surface tension phenomenon described above, thereby lessening, rather than increasing, the bridging capabilities of the emulsion.

Coater Blade Thickness

Perhaps the best way to approach a discussion of the influence of coater blade thickness on the thickness of the emulsion coating would be to cite an analogous relationship between squeegee angle and ink film thickness. It is well known that as the squeegee passes across the screen during the act of printing, variations in the angle at which it is held will cause either more or less ink to pass through the screen onto the substrate.[1] Specifically, the smaller the angle between the leading edge of the squeegee and the screen, the thicker the ink film deposited. As the leading edge of the squeegee forms an acute angle with the screen, so the leading edge of the coater blade, while the emulsion is being applied, forms a similar angle to the screen. Since all coater blades are rounded along the contact edge, it follows that as blades increase in thickness, the degree of roundness of that edge, or the arc described by it, will be greater. As a consequence of this, if a thin and a thick blade were held at the same angle to a screen, the contact angle--the angle formed between blade and screen closest to the point where they touch--would be greater for the thin than for the thick blade. We could therefore expect the latter to deposit more emulsion than the former.

FOOTNOTES TO CHAPTER IV

1. Kyle, "Modern Photostencil Methods, Part 6," 60.

2. For an analysis of squeegee action during printing, see E. J. Kyle, "High Definition Printing-Part 6," _Screen Printing_ (November, 1972). 26 - 28, 52.

CHAPTER V

HYPOTHESES

On the basis of these theoretical considerations it is hypothesized that different degrees of edge definition, or concavity, will result from different levels of each of the variables of emulsion thickness, mesh count, thread diameter and coater blade thickness; and it is further hypothesized that differences in the amount of concavity will result from interactions between these four variables. Stated in null form the hypotheses are as follows:

1) There will be no difference in the degree of concavity present in direct stencils consisting of single, double and triple emulsion coatings.

2) There will be no difference in the amount of concavity present in direct stencils made on screens of 123, 186 and 230 mesh.

3) There will be no difference in the degree of concavity present in direct stencils made on screens of thin, medium and thick thread diameters.

4) There will be no difference in the degree of concavity present in direct stencils coated with either a thin or a thick coater blade.

5) There will be no interaction between the variables of emulsion thickness, mesh count, thread diameter and coater blade thickness.

CHAPTER VI

METHODOLOGY

It was determined at the outset that in order to be meaningful, the study would have to entail at least three levels of most of the variables named at the close of the previous chapter. The three thread thicknesses, S, T and HD have already been discussed and need no further explanation here. As for mesh count, the ability of fine-mesh screens to effectively eliminate poor edge definition is already known; therefore, it would serve no purpose to include these in the study. Rather, we are concerned about the relationship of all the other factors to coarse and medium screens. In light of this, the screens to be tested were selected from the center of the coarse range (approx. 120 mesh), the center of the medium range (approx. 220 mesh) and intermediate between the coarse and medium ranges (approx. 170 mesh). The exact mesh counts were 123, 186 and 230. Three levels of emulsion coating were also tested, since a primary object of the study was to learn whether stencils of good edge definition can be achieved on relatively coarse screens without applying more than one or two coatings. The levels tested were single, double and triple (or multiple) coatings of emulsion. As for the fourth factor, coater blade thickness, it was determined that only two levels need be studied. There were two reasons for this, First, the introduction of a fourth three-level factor to a study such as this would have made the statistical analysis of the data too cumbersome to be practicable. Second, if the coater thickness did make a difference in the edge quality of the stencil, then that difference would show up in a comparison of the effects of the two coaters, and the introduction of a third would have made no useful contribution. The specific thicknesses of the coaters used were .066" for the thin coater and .160" for the thick coater.

It was further determined that in order to place the experiment on as firm a scientific footing as possible, it would be given a statistical design, and its results would be subjected to statistical analysis. A factorial design was chosen, as this method lends itself most readily to the kind of multi-levelled study in question.

Rickmers and Todd define the factorial design as "one by which we obtain the same number of observations (one as a minimum, more if we desire more) for each level of the tested factor."[1] Their discussion of the efficacy of the factorial method is worth quoting in full.

> Factorial experiment designs are superior to controlled experiments in many respects:
>
> 1. We can study the effects of several factors in the same set of experiments.
> 2. We can test for the effect of each factor at all levels of the other factors and can discover whether or not this effect changes as the other factors change.

3. We can test not only for the effects of the factors separately--the main effects--but also for interactions--joint effects of two or more factors combined.
4. Every judgment we make about the effects of the factors is based on all the observations accumulated in the entire set of experiments, not merely on a few of the observations. Thus factorial experiments are...sensitive in the detection of small effects.[2]

As is already known the variables to be studied were 1) emulsion thickness, 2) mesh count, 3) thread diameter and 4) coater blade thickness. The fact that the first three of these variables were to be observed at three levels suggested that the experiment be designed as a three-factor, three-level factorial--a three-to-the-third (3^3) factorial--and that it be carried out twice: once in the presence of the first level of factor four, and again in the presence of the second level. Schematically, the experiment would take the following form:

		Single emulsion coating			Double emulsion coating			Triple emulsion coating		
	Mesh count	123	186	230	123	186	230	123	186	230
Thread Thickness	S									
	T									
	HD									

Figure 2. Schematic Depiction of 3^3 Factorial

The experiment required the use of two sets of nine screens each. Each set contained screens of the following mesh-count/thread thickness combinations: 123S, 123T, 123HD;

186S, 186T, 186HD; and 230S, 230T, 230HD.

All screens were stretched expressly for this experiment, using a pneumatic screen stretching system. Since this system permits precise control of the amount of screen stretch, either by stretching several screens simultaneously or by stretching succeeding screens to exactly the same degree, any effect that variations in screen tension might have would be minimized. And to further insure that such variations would not occur, screen tension was checked with a tension-measuring device during the stretching procedure. As soon as each screen was securely adhered to its frame, a label was affixed to each frame, showing the mesh count and thread thickness of the fabric it held.

With the thinner of the two coaters each of the first set of nine screens was coated with emulsion in three separate but adjacent areas: in the first area with a single coating, and in the other two areas with a double and triple coating respectively. For the purposes of this experiment, a single coating consisted of two applications of emulsion on the job side of the screen, with the screen turned 180 degrees between applications; followed immediately by two more applications on the squeegee side, again with the screen turned 180 degrees between applications. A double coating consisted of the above, with an additional coating on the job side after drying; and a triple coating consisted of yet another coating on the job side after the second coating had dried.

Coating was carried on in three stages, the first of which consisted of the application of the initial layer of emulsion to all the screens. Immediately after this first application, pieces of tape marked I, II and III respectively were placed on each frame adjacent to the coated areas, according to the number of layers each would ultimately receive. Obviously. this procedure facilitated keeping track of which stencils contained how many emulsion thicknesses. At the same time the frames were labelled to identify which coater blade was used to coat the screens. Drying was carried on under uniform conditions; that is, each screen was fan dried with cool air in a horizontal position, job or emulsion side down. After the initial application had dried, a second coating was applied to areas II and III. These were dried a second time, as before, but with the emulsion side up. Again, after drying, a third coating was applied to area III and was dried.

The same procedure was followed on the remaining nine screens with the thick-bladed coater. Once the coating process was completed, each screen had three stencils on it, consisting of single, double and triple layers of emulsion respectively.

The next step was to expose the screens. Because each screen held stencils of varying thicknesses, it was necessary to predetermine the exposure for each of the stencil thicknesses by means of testing. Before the experimental stencils were exposed, therefore, two test screens were prepared in the manner described above, one with each type of coater. These were exposed to the same test target that was used in the experiment: a figure based upon Kyle's test target, but containing fewer and simpler elements. That is, is consisted of two clusters of straight lines at right angles

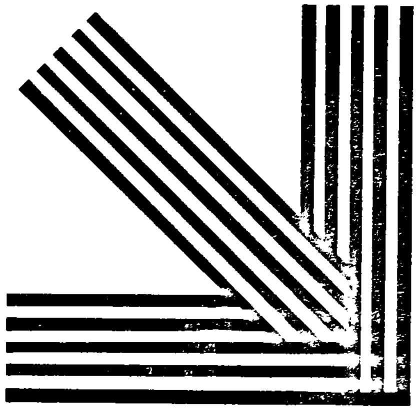

Figure 3. Test target used to expose the screens

to each other, with a third cluster radiating from the apex of the angle formed by the other two, at a 45-degree angle. Thus the target retained the overall quarter-circle configuration of Kyle's test target, but contained fewer radial elements. Further, each cluster consisted of a series of continuous elements running the length of the cluster, rather than several small units arranged according to size (Figure 3).

This target allowed for the evaluation of image edges that ran along the warp and weft of the screen fabric, as well as those that crossed the threads diagonally.

During the test exposure, each stencil was given a series of stepped exposures so that varying degrees of emulsion hardening would take place. Of course while any one stencil was being exposed, the other two were protected by the placement of an opaque sheet over the vacuum frame glass. Once the optimum exposures for the emulsions of all three thicknesses were determined, each experimental stencil was exposed for exactly the same time.

The light source for exposing the stencils was a 4000 watt metal halide lamp. During exposure the screens were placed in a soft-blanket vacuum frame with the film positive on the glass, emulsion up, and the screen on the positive emulsion down, thereby insuring emulsion to emulsion contact between positive and stencil. After exposure all stencils were developed, or washed out, in the following manner. A plate-developing sink was filled with water of 100 degrees Fahrenheit to the depth of one quarter inch, and the exposed screen was placed in the water, emulsion down, and allowed to soak for one minute. At the end of this time one end of the screen was raised, the sink was drained, and the stencil was washed out with a gentle spray of 100 degree water on both sides, until all unhardened emulsion was dissolved. The screens were then fan-dried with cool air.

With the drying of the stencils the procedure of screen preparation was completed, and the task of evaluating edge definition began. The tool for accomplishing this was the DuMaurier Micromike 40K microscope. This is an ideal instrument for observing stencils, since it is designed to be placed directly in contact with the screen, and has in its optical system a calibrated scale, which can be used to measure whatever is under observation.

What was observed was the configuration of stencil edges of two types. The first was that which followed the direction of the screen threads but that ran across successive mesh openings, touching the screen only where it crossed threads that ran perpendicular to its own direction (Type 1). The second type crossed the screen mesh diagonally (Type 2). Obviously, the reason for distinguishing two types of stencil edge was to evaluate what might be called general edge definition, as well as to observe the effect the variables under study had on sawtoothing. Of course, data for each type of stencil were recorded on separate data tables.

In the case of the Type 1 stencil edge the specific configuration studied was that which occured from a point midway across a thread running perpendicular to the direction of the stencil edge to the point of the stencil's greatest recession in an opening between two such threads. These points are illustrated in Figure 4 as A and B respectively.

The response variable--the variable which yielded the data point upon which all subsequent analyses and conclusions were founded--was the distance in microns between the imaginary line C (an ideal stencil edge) and point B in Figure 4. This distance was measured on the micron scale built into the microscope, and the number that constituted this measure was used to quantify the response variable for all the screens.

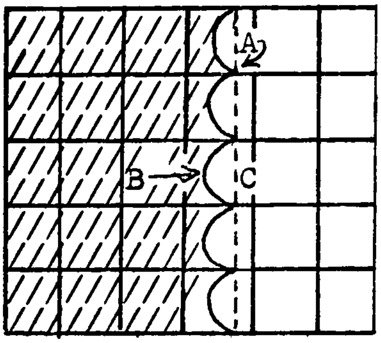

Figure 4.
Type 1 Stencil Edge

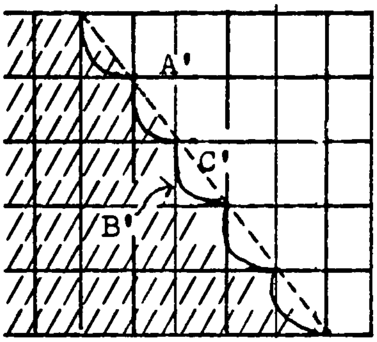

Figure 5.
Type 2 Stencil Edge

Essentially this same procedure was used to evaluate diagonal stencil edges. In this case the configuration observed was that between points A' and B' in Figure 5, and the distance measured was C' - B'. For the sake of consistency, the point of greatest recession was always coupled with a point that crossed a thread above it, as points A and A' lie above points B and B' in Figures 4 and 5 respectively.

One point needs to be clarified here. It was implied above that a single C - B, or C' - B', measurement corresponded to a data point for record. Actually, the number recorded represented an average of several--at least three--samples of recession.

After all the data were assembled, they were subjected to an analysis of variance, so that the significance, not only of each individual variable, but of all the variables in all their combinations, could be determined.

FOOTNOTES TO CHAPTER VI

1. Albert D. Rickmers and Hollis N. Todd, *Statistics: An Introduction* (New York: McGraw-Hill Book Company, 1967), p. 310.

2. Rickmers and Todd, p. 310.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The data for each of the four kinds of observation discussed in the previous chapter are given in Tables 1 - 4, and as indicated earlier, represent the distances between points C and B in the Type 1 stencils and C' and B' in the Type 2 stencils. Thus, in Table 2, the number 2.5 in the S

Table 1

		Single emulsion coating			Double emulsion coating			Triple emulsion coating		
	Mesh count	123	186	230	123	186	230	123	186	230
Thread Thickness	S	1.5	0	0	0	0	0	0	0	0
	T	0	0	0	0	0	0	0	0	0
	HD	0	1.5	0	0	1	0	0	1	0

Summary of data obtained from Type 1 stencil, applied with thin-bladed coater

Table 2

Thread	Thickness	Single emulsion coating			Double emulsion coating			Triple emulsion coating		
	Mesh count	123	186	230	123	186	230	123	186	230
	S	2.5	0	0	2.5	0	1.5	0	0	2
	T	3	0	0	3	0	0	3	0	0
	HD	0	2	0	0	0	0	0	0	0

Summary of data obtained from Type 2 stencil, applied with thin-bladed coater

Table 3

Thread	Thickness	Single emulsion coating			Double emulsion coating			Triple emulsion coating		
	Mesh count	123	186	230	123	186	230	123	186	230
	S	0	0	0	0	0	0	0	0	0
	T	2	0	0	0	0	0	0	0	1.5
	HD	2	1	1	0	1	0	0	0	0

Summary of data obtained from Type 1 stencil, applied with thick-bladed coater

Table 4

		Single emulsion coating			Double emulsion coating			Triple emulsion coating		
	Mesh count	123	186	230	123	186	230	123	186	230
Thread Thickness	S	2.5	2.5	1.5	2	2.5	1	2	2.5	1
	T	3	1.5	0	3	1.5	1.5	2.5	2	0
	HD	3	1.5	1	2.5	2	0	2	1.5	0

Summary of data obtained from Type 2 stencil, applied with thick-bladed coater

row and 123 column under Single emulsion coating represents an average sample stencil edge concavity of 2.5 microns from the ideal. Likewise, the two zeros immediately to the right of that figure represent no deviation of the samples taken for the S thickness of the 186 and 230 mesh screens that received single coatings of emulsion.

It can be seen at a glance that the data exhibited in Tables 1 and 3--representing Type 1 stencil edges made with thin and thick coater blades respectively--consist almost entirely of zeros. One hardly needs to perform a statistical analysis of these data to conclude that for the particular stencils in question, variations in mesh count, thread diameter, coater blade thickness and emulsion thickness resulted in no difference in the quality of edge definition obtained. Nevertheless, an analysis of variance was done for each of the two sets of data, and the results corroborated the conclusion of no difference.

A somewhat different situation exists, however, with regard to the data gathered in Tables 2 and 4, representing definition in Type 2, or diagonally-oriented, stencil edges. Clearly, Table 4 shows a good deal of deviation from the ideal. But in Table 2, in spite of a certain amount of deviation, a substantial number of zeros casts doubt on whether that deviation is meaningful enough to represent a real difference.

Again, an analysis of variance was performed on each of these sets of data, with a 5% probability of error. The results indicated that of the three factors of mesh count, thread diameter and emulsion thickness, mesh count alone was significant. That is, the particular variations in thread diameter and emulsion thickness that were used in the experiment were insufficient to produce differences of definition in Type 1 stencil edges. But the variations in mesh count that were introduced did result in differences in edge definition quality.

As for the fourth factor, coater blade thickness, the experiment did not yield data that showed clearly whether differences in blade thickness had any effect on edge definition. It is true that of the two sets of stencils in which differences were detected, one was applied with a thin coater blade and the other with a thick blade. One would be inclined to conclude from this circumstance that variation in coater blade thickness was not a factor in the differences that occured in edge definition. However, further analysis of the data showed that

1) among the stencils made with the thin blade, the greatest differences occured between those made on the 123 and 186 mesh screens, and

2) among the stencils made with the thick blade, the greatest differences occured between those made on the 186 and 230 mesh screens.

Thus, while it can be concluded with a reasonable degree of certainty that variations in coater blade thickness *per se* had no bearing on the differences detected in edge definition, it is unclear whether those variations, or some other factor, influenced the two *kinds* of difference observed.

On the basis of the foregoing analysis, the following conclusions, stated in terms of the hypotheses set forth in Chapter V, have been reached:

In the experiment described in this paper

1) there was no difference in the degree of concavity present in stencils consisting of single, double and triple emulsion coatings;

2) there was a difference in the degree of concavity present in stencils made on screens of 123, 186 and 230 mesh. However, these differences were present only in stencils whose edges ran diagonally to the screen thread direction.

3) There was no difference in the degree of concavity present in stencils made on screens of thin, medium and thick thread diameters.

4) There was no difference in the degree of concavity present in stencils coated with either a thin or a thick coater blade.

5) There was no apparent interaction between the variables of emulsion thickness, mesh count, thread diameter and coater blade thickness; that is, no combination of any or all of these variables accounted for any differences in edge definition.

Thus the null hypotheses numbered 1, 3 and 4 (in Chapter V) have been accepted. Hypothesis number 5, relating to interaction, can neither be accepted nor rejected, on the basis of insufficient data. And Hypothesis number 2 has been rejected, since mesh count did indeed make a difference in the quality of edge definition.

What all this means in practical terms is that, on a coarse screen and with a single coating of emulsion, there was obtained a direct stencil which had good edge definition, wherever that edge paralleled thread direction.

Definition of equal quality was obtained in stencils made on screens intermediate between coarse and medium, when the emulsion was applied with a thin-bladed coater; and only in stencils made on medium screens, when a thick coater blade was used to apply the emulsion.

No claims are made here, regarding the repeatability of any of these results under ordinary shop conditions. Nevertheless, the fact that good edge definition was obtained on a coarse screen with only a single coating of emulsion will perhaps be of interest to commercial screen printers.

CHAPTER VIII

RECOMMENDATIONS FOR FURTHER STUDY

In view of the results obtained, it is recommended that the following additional studies be made:

1) a study designed to determine how thin a coating of emulsion will yield stencils with edge definition comparable in quality to that obtained in the Type 1 stencils described above;

2) a study designed to determine the coarsest screen upon which a single coating of emulsion will yield a Type 1 stencil of good edge definition;

3) a similar study for a Type 2 stencil;

4) a study to determine conclusively whether coater blade thickness does or does not influence stencil edge definition.

During the development of the present experiment, the question was raised as to whether the response factor--a raw unit of distance--would result in a distortion of data when used to record phenomena occuring in screens of differing mesh counts; or whether the response factor should be somehow converted to account for the differences in mesh count, and thereby neutralize any possible distortion effect. The question was deemed to be a valid one, but it was felt that the attempt to answer it would go beyond the scope of the present inquiry. Therefore, it is recommended here that a study--or perhaps two separate studies--be made a) to determine if the need exists for such a conversion of data, and if so, b) to devise a method of making such a conversion.

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APPENDIX

PRODUCTS AND SPECIFICATIONS

The following is a list of products used and specifications followed in this experiment.

Screen fabric: Nytal monofilament nylon, Swiss Silk Bolting Cloth Manufacturing Company

Stretching equipment: Four three-foot Stretch-Air-Bars, American Screen Process Equipment Co.

Emulsion: Azocol "R" direct photo emulsion

Coating procedure: Two coats squeegee side, each in opposite directions; two coats job side, each in opposite directions.

Coater blades: Thin: Aluminum scoop coater, .066"

Thick: Aluminum scoop coater, .160"

Vacuum frame: American Polycop Direct Contact Photo-Screen Exposing Unit, 39 x 52.

Light source: NuArc 4000 U.P. printing lamp

Exposure times: Single coat, three minutes; double coat, five minutes; triple coat, seven minutes: all with lamp three feet from emulsion.