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An Evaluation of the effect of registration on GCR and conventional chromatic separation methods in multicolor halftone printing

Chihwe Jeffrey Wang

AN EVALUATION OF THE EFFECT OF REGISTRATION ON GCR AND CONVENTIONAL CHROMATIC SEPARATION METHODS IN MULTICOLOR HALFTONE PRINTING

by

CHIHWE JEFFREY WANG

B.S. Chinese Culture University

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Signature of the Author ______________________

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Dr. Edward M. Granger, Thesis Advisor

Joseph L. Noga

Dr. Chi Ming Tang

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A thesis submitted to
the Center for Imaging Science
in partial fulfillment of the requirements for
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ABSTRACT

Misregistration is an unavoidable problem in multicolor halftone printing. It causes the loss of detail, sharpness and color hue shift of a reproduction. However, there is a color separation technique called Gray Component Replacement (GCR) which may reduce or eliminate this misregistration effect. An investigation had been conducted using a series of color halftone proofs which were produced by conventional chromatic and GCR color separation techniques. The subjective image quality scaling method was applied to this study as a criterion to determine whether there is an image quality relationship between these two techniques on misregistered reproductions.

ChapterI. INTRODUCTION

Accurate control of registration on press and throughout the printing process is one of the necessary factors in achieving a successful color reproduction from a color original using any printing process. Although screen ruling, ink, tone reproduction and paper are all important factors that contribute to the final result of a reproduction, registration is still the main factor to be considered.

Since the inception of multicolor halftone printing, printers have found that misregistration is one of their major problems. It occurs everywhere, in color scanning, in film stripping, on the vacuum frame, on the copyboard of a camera, in plate making and on press.

There are several causes for misregistration to occur, including manual misregistration of the four color halftone separations, the temperature and humidity changes on paper and film base materials, dynamic unbalance and gear eccentricity of a press (cyclic variations), inconsistant strain between printing units, hardness of blanket on the press, cylinder velocity variations and in feed tension variations. Any errors in the above factors can cause detail loss and color variations in any color reproductions due to misregistration.

Can Gray Component Replacement(GCR) contribute anything towards solving the misregistration problem? GCR is a new trend in color reproduction, but not a new idea. Thirty seven years ago, John Yule in a TAGA report defined the gray component as "the maximum amount of black ink which can be substituted for the yellow, magenta and cyan of an accurate three-color-reproduction in any area without degrading the color"(Ref.1).

In the conventional chromatic color reproduction method, all color hues of an original, as well as black and neutral gray, are produced by the three primary printing inks, yellow, magenta and cyan. They are then stabilized by black ink which adds depth to the shadows and darkens the grays. The black has minimum impact in terms of color.

In the GCR method, the yellow, magenta, and cyan colors are formed in the same way as in chromatic reproduction, but the rest of the colors are formed by two process color inks and black ink. Black ink adds grayness and darkness to the image, and is also the dominant color ink in gray and black areas. The function of GCR is to remove the third contaminant color ink and an equal amount of the other two color inks in a combination of three complementary color inks and the third color ink is replaced by black ink.

The black printer in GCR method carries more of the information, detail and drawing in selected areas of the reproduction than in conventional chromatic method, and black as the dominant color ink, covers most outlines of an image and maintains a stable gray balance; therefore registration problems are reduced.

Maintaining gray balance is extremely important in color reproduction. As studies have shown that without the proper gray balance, it is impossible to expect to have true color reproduction. Gray balance is a reference to have the appropriate dot size and the correct ink density for yellow, magenta, and cyan. It enables us to reproduce a gray scale as a perfect neutrality gray scale (no color cast).

The assumption of gray balance is that if people could achieve the perfect balance of dot area and ink density to produce the gray scale with perfect neutrality, people would have the proper conditions to make it possible to reproduce color areas to match the color of the originals.

One advantage of the GCR method is that the gray balance is perfectly stable, even if there are some shifting in the amount of black ink. The shifting will make the gray tones and color values a little lighter or a little darker. But the colors will not be adversely affected at all. On the other hand, the fluctuations of the three process color

inks will have no influence on the gray balance since the neutral tones will only get such values of yellow, magenta, and cyan inks, which are necessary to form the needed colorcast.

ChapterII. OBJECTIVES

As discussed before, in the GCR color separation method, the black printer carries more of the information, detail in certain areas of the reproduction than in conventional chromatic method, and covers most outlines of an image and maintains stable gray balance. So, GCR color separation method minimizes misregistration effects in multicolor halftone printing.

The hypothesis of this study is that the image quality of a misregistered reproduction can be improved using the GCR method. When the magnitude of misregistration of a reproduction is under certain "mm", this reproduction is still acceptable by most of the people.

The objectives of this study are: (1) to determine whether there is any image quality improvement or loss due to misregistration using the GCR color separations compared to the conventional chromatic separations; (2) to decide the acceptable misregistration magnitudes of a reproduction in conventional chromatic and GCR separations; (3) to investigate which of these color inks, yellow, magenta, or cyan has the least or most impact of misregistration in a reproduction.

Chapter III. LITERATURE REVIEW

1.Registration

1.A. Theory of Registration

The basic theory of registration is to locate a plane in a wanted space precisely. One must assume that a plane has already been established in which the registration should take place.

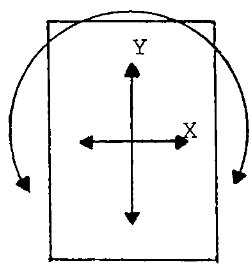


Figure 1. Directions of Movement in a Flat Sheet

Figure 1. indicates that the flat sheet has three directions of movement as shown by the arrows. There are two directions of movement in the X and Y axes, and one direction of movement in rotation. When all the directions of movement have been stabilized, the flat sheet will be firmly located in the reference plane.

1.B. Problems of Registration

1). Film Stripping

To understand the misregistration problems, we need to look at film stripping, plate making, and press work in multicolor halftone printing to know how the registration is produced. In the film stripping process, registration is maintained by a pin system and visual overlapping. Overlapping the four color separations is done manually. Misregistration may occur due to human error.

2). Plate Making

In the plate making process, it is important to secure the positional accuracy of the screened films to be printed on the plate. Such accuracy can be achieved either by using an automatic photocomposer, or by attaching the screened films manually. The first method involves less misregistration than the second. In the second method, a thin template is laid on a plate and marked off with the position reference marks by a marking-off pin. Misregistration may happen in this manual operation.

3). Press Work

In the press work stage of the process, misregistration may be caused by erroneous mounting of printing plate on the cylinder of the press or by phase error of the cylinder, or by a mechanical deficiency in the press.

Many techniques and electronic devices have been invented, such as pin registration systems (Ref.2), digital registration machine (Registar) (Ref.3), automatic presetting systems (Ref.4), electronic register system (Ref.5), and so on, to solve the misregistration problems in multicolor printing process. But little can be done when misregistration already exists in the previous step of printing processes.

2.Misregistration in Dot-on-Dot Printing

Dot-on-dot halftone printing is a process in which each separation of yellow, magenta, cyan, and black is produced by using only one screen angle in the color separation procedure. Therefore, every single dot of each separation will form all the colors (excepting yellow, magenta, and cyan colors) of a reproduction because they overlap with each dot centrally on the printed material. When misregistration happens in dot-on-dot halftone printing, those dots can not be overlapped exactly centrally, different part of dots overlapped with each other to produce different color combinations on a reproduction. The color hue of this misregistered reproduction will shift when compared with the original.

Studies have shown that color shifts produced by misregistration of halftone dots are not objectionable, if the magnitude of misregistration is under or equal to 1/4 dot size in a 65 line/inch screen ruling dot-on-dot halftone

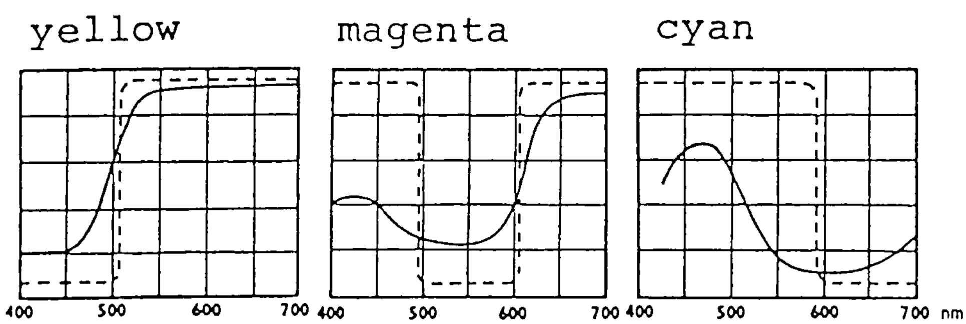
printing (Ref.6). Since dot-on-dot multicolor halftone printing is extremely sensitive to minute variations in registration (Ref.7). A one fourth dot size magnitude of misregistration is still acceptable in dot-on-dot printing. The misregistration magnitudes of one fourth, one half, one, one and half, and two dots of a 50% dot size in 65 line/inch screen ruling are reasonable choices to observe in multiple screen angle printing of this study.

3.Color and Ink

The conventional chromatic three-color-printing is based upon the subtractive color theory principles. In the subtractive color mixing process, yellow, magenta, and cyan are printed on top of each other to produce a neutral black. Multicolor halftone printing is using the same process, because the dots of the yellow, magenta, cyan, and black printers are so small that the eyes can not resolve them individually making them appear as a continuous tone of color.

Transparent printing inks work as filters. They permit the subtractive physical mixing of the color to take place on the printed surface. White light penetrates the transparent ink film where it is diffused on the white paper surface and reflected back through the surface of the ink film. The sensation of color is thus created by putting ink in direct contact with the paper.

Due to the fact that up to four layers of ink are deposited onto the paper's surface, drying and ink trapping become even more critical. Another problem is the overprint of these three color inks (yellow, magenta, and cyan) which cannot produce a satisfactory black because they contain unwanted absorptions and thus have no ideal spectral curves. Figure 2 shows the spectral response of three inks (yellow, magenta, and cyan). It also shows the shortcoming of using only three color inks. Therefore a black ink is necessary to give darkness and depth of color (Ref.8).



Actual process ink reflection ----------

Ideal process ink reflection - - - - - - -

Figure 2. Spectral Response of Printing Inks

4.Gray Component Replacement

In 1940 Yule stated that "if suitable corrected negatives could be made easily, the best results would usually be obtained by using the maximum possible quantity of black, and printing not more than two of the three subtractive colors at any one point" (Ref.9). In 1954, Tobias said that "any color within the gamut of the four-color process printing inks can be reproduced by pairs of the chromatic inks plus black ink. The chromaticity of a color will vary with the two chromatic ink mixtures, whereas luminance is affected by the amount of black ink used" (Ref.10).

The GCR theory of color reproduction is based on the concept that it is unnecessary to use three basic inks, yellow, magenta, and cyan to reproduce a neutral component or value which could be obtained by using appropriate proportions of black (Ref.11). In conventional three-color halftone printing, whenever a color is produced by some combination of yellow, magenta, and cyan inks, the two predominant colors determine the hue of that area. The least dominant color darkens and provides "shape".

For example, in a red that is produced with halftone values of 95% magenta, 80% yellow, and 20% cyan, the cyan becomes the least dominant primary color. Since cyan absorbs red light, it will darken or "dirty" the red color. Cyan dots in a red area will look black, magenta dots in greens and yellow dots in blues have the same darkening

effect. Therefore, we can separate the printing of yellow, magenta, and cyan into two separate components: the color values and the gray values. Color values could consist of one color or two fundamental colors, whereas, gray values consist of equal amounts of yellow, magenta, and cyan.

4.A. Functions of GCR

The principle of GCR is to remove the color inks which contribute the least dominate color in an image and darken the hue of printed colors. Those color inks will be replaced by a computed value of black ink. The black, in this theory, also replaces the color inks in the neutral shadow areas. In the following section, three colors: red, green, and blue were chosen from a color guide will be discussed in the GCR and the convention chromatic separations. Each of them has a number to represent its color appearance.

1). The Red Area

A red area, in conventional chromatic color separation method, is produced by the combination of magenta and yellow with the cyan providing the darkening and shape. For example, red 38 is in a color combination of 100% magenta, 80% yellow, and 30% cyan (Ref.12). The color separations to produce this red 38 in three-color halftone printing are made according to these color percentages in the conventional chromatic color separation method. But in the GCR color separation method, 30% black will be used in stead of using a combination of 30% magenta, 30% yellow, and 30%

cyan to provide the darkening and shape. Color values for magenta and yellow are 70% and 50%. The following diagrams illustrate these two methods.

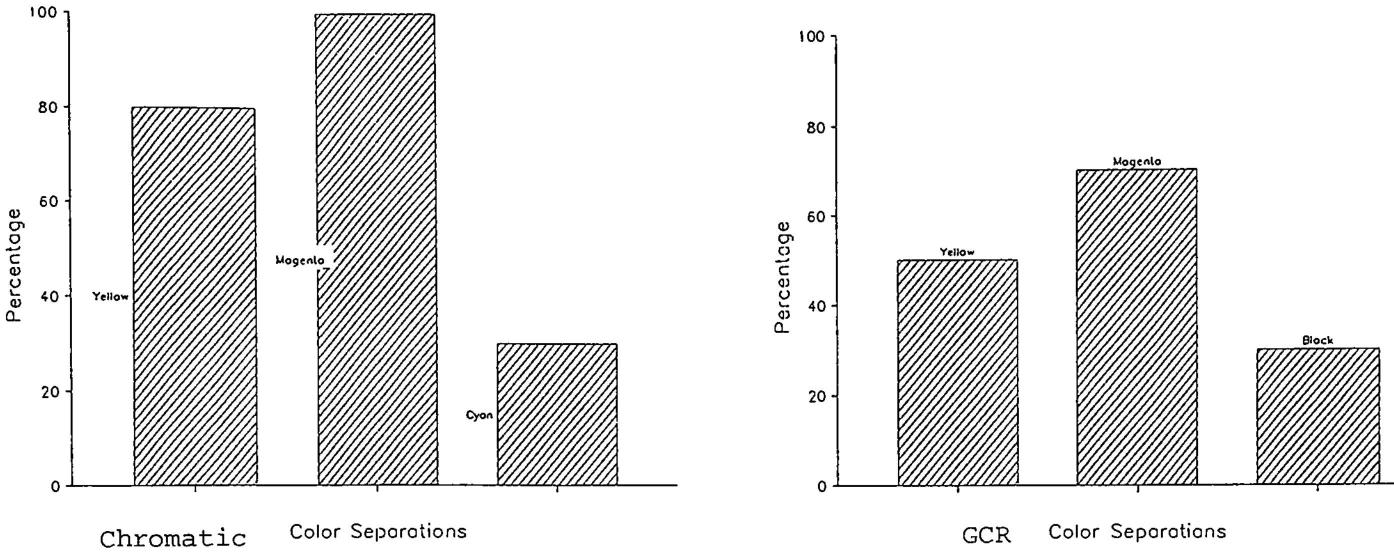


Figure 3. Percentages of Color in Separations.

2). The Green Area

The color value is provided by cyan and yellow, using magenta to produce darkening in the conventional chromatic separation. Green 201 consists of 100% yellow, 100% cyan, and 10% magenta (Ref.13). These are also the color percentages of each color separation in the conventional chromatic method. In the GCR color separation method those color values are 90% yellow and 90% cyan with 10% black. There is not any percentage of magenta existing. The following diagrams illustrate these two methods.

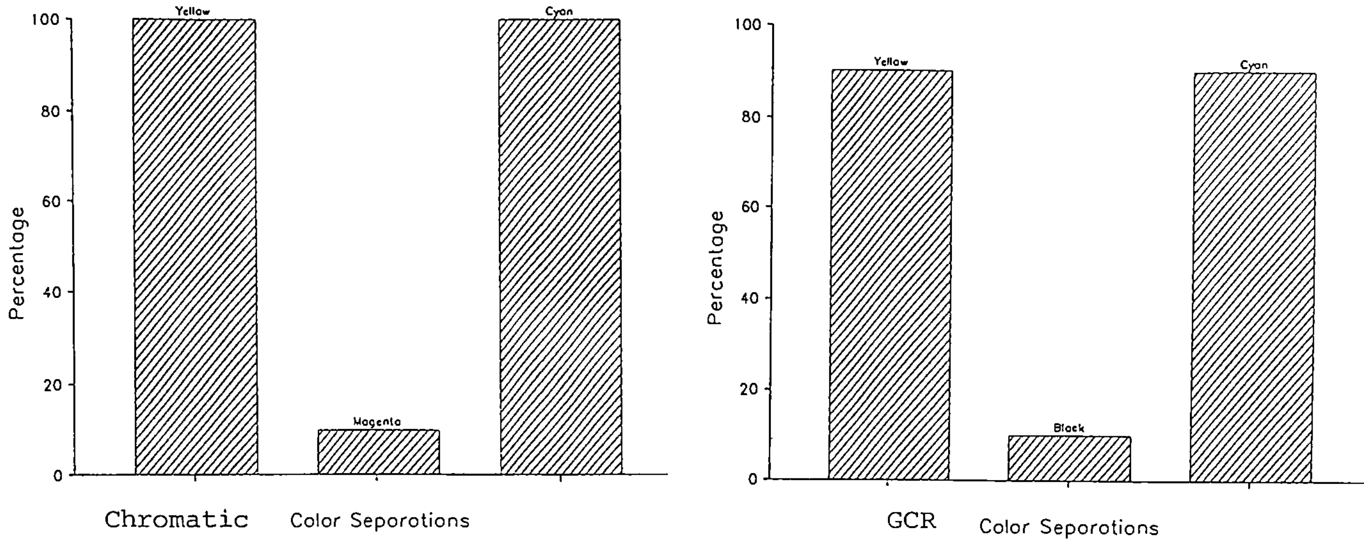


Figure 4. Percentages of Color in Separations.

3). The Blue Area

The color value is produced by cyan and magenta with yellow providing the darkening and shape in conventional chromatic method. Blue 220 consists of 100% cyan, 60% magenta, and 10% yellow in the conventional chromatic separations (Ref.14). But using the GCR method to produce this certain color, there will be only 90% cyan and 50% magenta with 10% black.

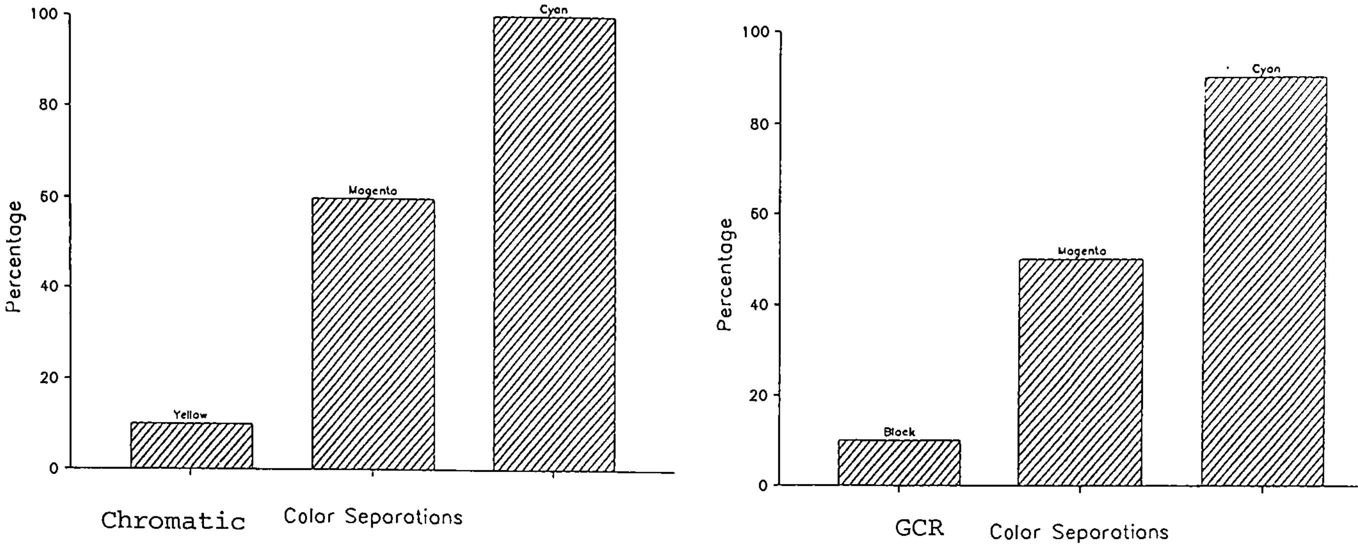


Figure 5. Percentages of Color in Separations.

4). The Brown Area

A brown area, in conventional color, is produced by the combination of yellow and magenta with the cyan providing the darkening and shape. In GCR the cyan is replaced by black. There is also a reduction in the yellow and magenta because a percentage of both combined with the cyan was actually producing a gray component in the color. The black ink now provides that gray component. The resulting reduction in total ink laydown in the dark browns also helps reduce ink trapping and drying problems.

5). In A Dark Green Area

In a dark green area, yellow and cyan are the two predominant colors. If the magenta increases in value due to an increase in density, or dot gain on the press, there is a hue shift in the green. With GCR , the color value is

still provided by the yellow and cyan but now the darkening is provided by the black. If the density of black increases or dot gain occurs, there is still a change, but because black is being added to the color value as opposed to magenta, it only produces a darker shade of the same green hue. That translates to more consistency and latitude when printing color.

6). In A Purple Area

In a purple area or a dark blue, yellow ink provides the darkening and shape in conventional color. It is clearly more efficient to use black ink instead of yellow ink.

4.B. Effects of GCR

Gray Component Replacement can be applied in various degrees from 0% to 100%. As much as 100% GCR was used in this study. It means that the color inks which contribute to darken the hue of the printed colors of a reproduction were removed totally, instead, black ink was used. The neutral grays which were produced primarily by black ink become much more consistent.

Using 100% GCR, the neutral shadows have no yellow, magenta, and cyan at all. Therefore, when the black is out of registration with the other three colors, there is nothing under the black but white paper. A white line

around the image is apparently noticeable in black misregistration. This has been proven to be true that the misregistration of black with the other three colors in 100% GCR causes the significant loss of image quality. This study is only in reference to the yellow, magenta, and cyan out of register with the black to see the implications (Ref.15).

By using black, as opposed to the least dominant of a color image the gamut of color that can be reproduced actually increases. Ink trapping and drying problems are also reduced and more brilliant color can be printed by increasing ink value in saturated colors. B.A.Frost, in 1986 TAGA, stated that " GCR, also produces sharper looking images. No longer is exact registration of the three-color image required to provide the sharpness of the picture because now most of the detail and shape is provided by the black printer" (Ref.16).

5. Evaluation of Image Quality

5.A. Subjective Quality Factor

Subjective image quality scaling is an easily calculated and directly measurable method which gives consistent evaluations of system performance. It can predict image quality within normal reader error and is linearly correlated with the measured data. It provides a

quantitative way to evaluate and to express the image quality of a reproduction. Subjective quality factor (SQF) was used in this study to define the quality of images. Essentially, the higher the SQF value the better the image quality.

Schade in 1964 (Ref.17) found that the visual system's response to the luminous sine-waves resulted in a visual system modulation transfer function, MTF, in figure 6 which had a very broad resonancelike peak with maximum response at 6 cycles per degree, or 1 cycle per mm on an object viewed at 34 cm.

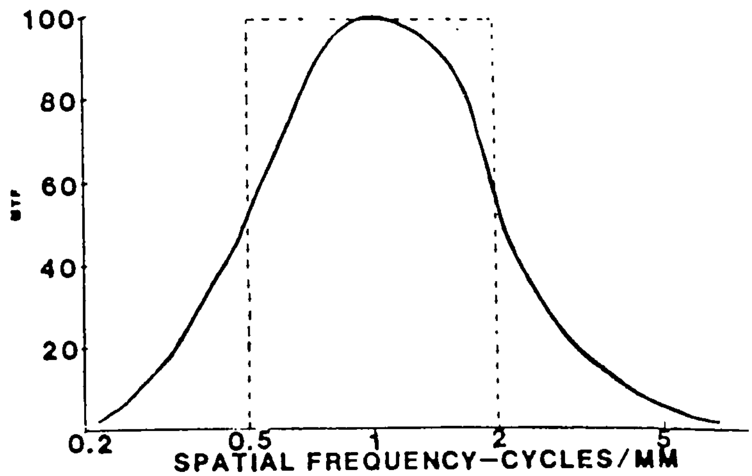


Figure 6.

SQF was defined so as to duplicate the operation of the human visual system. In figure 7, as illustrated, a spatial frequency region of 0.5 to 2.0 lines per mm is used (Ref.18).

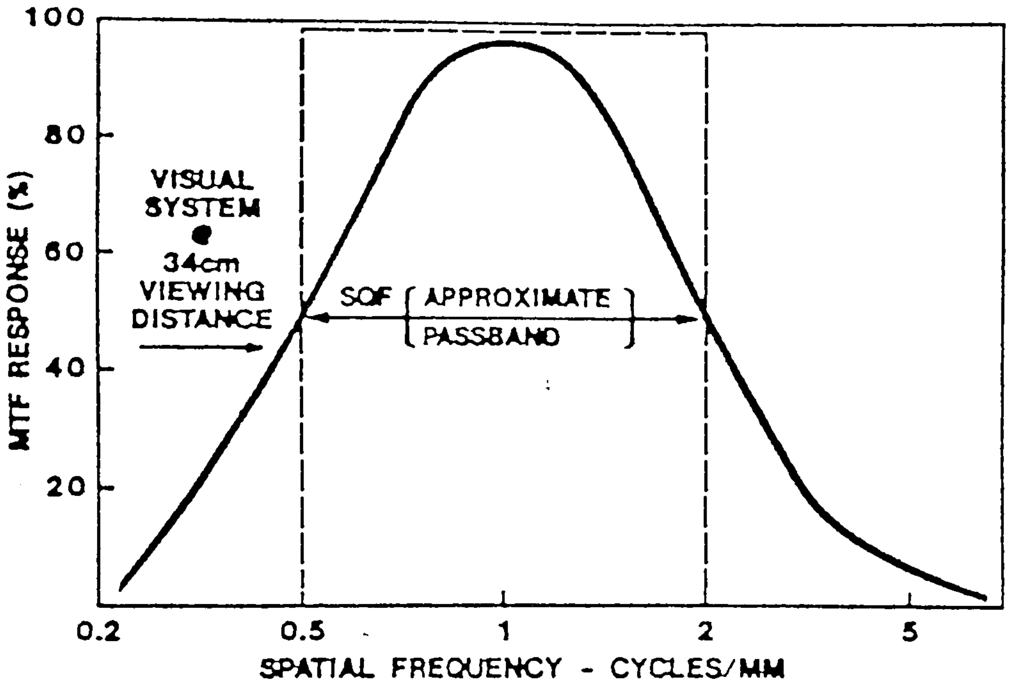


Figure 7.

In a two-dimensional imagery the SQF of color image quality can be calculated by:

$$S.Q.F. = K \int_{\ln (M/2)}^{\ln (2*M)} \int_{0}^{2\pi} \left| \int_{400}^{700} T(\ln f,\theta,\lambda) S_\lambda V_\lambda \, d\lambda \right| d\theta \, d(\ln f)$$

where $T(\ln f,\theta,\lambda)$ is the spectral O.T.F. in polar coordinate

form, S_λ is the spectral response of a neutral white display, and V_λ is the spectral luminosity function of the visual system. The wavelength, λ, is in nanometers. f is the spatial frequency in line per mm. M is the magnification used in viewing the image.

5.B. The Relationship Between Input and Output Image Quality

In a facsimile reproduction system, a linear relationship can be found in image quality between originals and reproduced images (Ref.19). A straight line can be determined as a reference to indicate quality of the reproduced images as figure 8 shows.

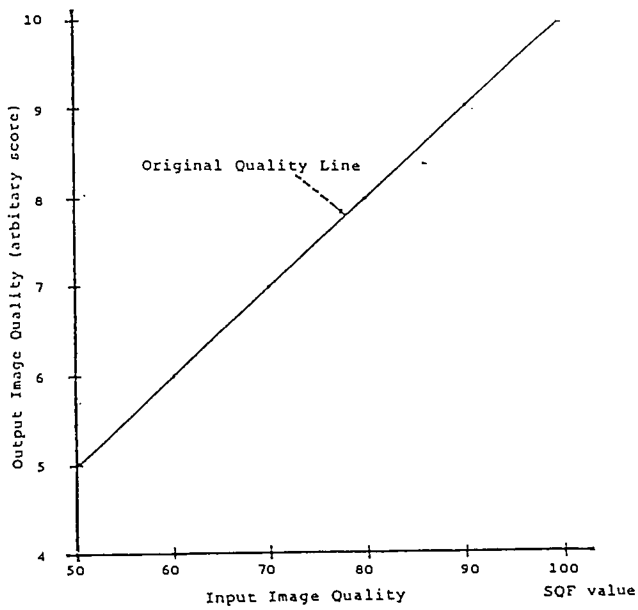


Figure 8.

5.C. Just Noticeable Differences (JND) in SQF

Subjective image quality is the result of subjective attributes, such as lightness, and sharpness, each of them

depends on one or more objective or physical quantities, such as solid ink density, and misregistration. The subjective image quality changed when the change of objective quantity happened. In order to find the relationship between subjective quality and objective quantities, one approach is to find what changes are required in the physical quantities of the image before an observer notices any changes in the image.

In this study, just noticeable difference (JND) data was performed as five SQF units (Ref.20). This value indicated the minimum changes in the physical quantities, misregistration magnitudes, that were recognized clearly by an observer. In the other words: it is noticeable, when the subjective image quality difference between precisely registered and misregistered proofs is larger than five SQF units. The JND value was used to establish minimum limits required for image improvement or degradation (Ref.21).

Chapter.IV METHODOLOGY

1.Preparation of Color Separations

The originals were three continuous tone color transparencies, a high-frequency image, a median-frequency image, and a low-frequency image. A high-frequency image contains many fine and small lines spreading all over the image without much space left. A median-frequency image contains about the same amount of small fine lines and space. A low-frequency image contains only a few small fine lines and a lot space.

A Screen ruling of 65 line/inch was used in this study, because it is the coarsest one in general use by the printing industry and make it easy to determine the misregistration.

Two sets of color separations for each originals were reproduced by electronic color scanning using the HELL DC-399ER with 100% GCR. Conventional chromatic and GCR color separation methods were used in 65 line/inch screen ruling. Screen angles were sixty degrees for yellow, one hundred and five degrees for magenta, one hundred and sixty five degrees for cyan, and forty five degrees for the black. Elliptical dot configuration was chosen in making a separation.

2.Preparation of Sample Proofs

The 3M Matchprint off-press proofing system was determined to be preferred over a press proof. The off-press proofing method eliminates the misregistration factors to a minimum and also offers an easier way to produce the desired registration. Because, there are too many variables in the press proof associated with every press run such as: dot gain, ink trapping, ink fluctuation, etc, off-press proofing system was used to give better control. After press proofs are made, it would be hard to identify the real causes of image quality variation which be made by misregistration or the other factors.

Six sample proofs were reproduced by 3M Matchprint Proofing System for three originals of two color separation methods with precise registration which means that the misregistration magnitude within each separation was less than 1/4 dot size in 65 line/inch screen ruling on a 50% dot area.

In order to evaluate the effect of misregistration for each color ink individually, only one color separation was allowed to misregister, with a specified magnitude, at one time. For instance, the yellow was misregistered at a magnitude, but the magenta, cyan, and black were registered with each other.

Before doing all the misregistered sample proofs, a test experiment had been done using only two misregistration magnitudes 1/4 and 1/2 dot size. Thirty six misregistered sample proofs were made under this condition of each separation (except black) for three originals and two separation methods.

Then a group of people, five persons, were asked to view those proofs randomly with a 30cm to 40cm distance and a D-50 light source viewing booth. All of them could not detect that there was a registration difference between proofs. This meant the misregistration magnitude of a halftone reproduction under or equal to one half dot size on 50% dot area is not noticeable by the human eye without any equipment in 65 line/inch screen ruling.

After this test experiment, fifty four sample proofs of three originals were made with three misregistration magnitudes (one, one and half, and two dots) for three color separations (yellow, magenta, cyan) using two separation methods (conventional chromatic and GCR). Each proof was made by only one misregistration magnitude of one color separation at a time. Every sample proof only has one color separation misregistered with the black separation which been always precisely registered. As a example, the yellow was misregistered with the magenta, cyan, and black separations.

All color sample proofs were reproduced by the 3M Matchprint II Positive Proofing System. It includes: 3M Matchprint Laminator, Olite Exposure System, Olix Light Integrator A1970, MR427 Positive Proofing Processor, and SWOP/GroupVI positive proofing film.

In order to have optimum resolution and density of reproductions, a 3M microline target was provided during each exposure to give a range of dots from two to ninety eight percent. The processing temperature of the MR427 processor was maintained between seventy four and seventy eight degrees Fahrenheit.

Totally there were sixty proofs been used in category analysis for this study, six of them were precisely registered and the others were misregistered with three different magnitudes. Since the size of a dot of 50% dot area in 65 line/inch screen ruling is equal to 0.2mm. Those misregistration magnitudes were 0.2mm, 0.3mm, and 0.4mm in terms of metric system.

All the proofs were trimmed to one size, seven by five and half inches, and mounted on a matte white cardboard with a size of eight by six and half inches before presented to the observers.

3.Subjective Visual Evaluation

All the facsimile reproductions: prints, proofs, printed materials, etc. were made to be viewed by human eye. And no proper device could be used in this study to observe the sharpness and detail change excepting human eye. So, subjective visual evaluation was used in this study to determine the image quality of those sample proofs. The image quality relationship between sample proofs using different color separation methods and misregistration magnitudes was derived by category analysis.

Thirty observers were chosen randomly from the general public to evaluate the image quality of sample proofs. A Macbeth viewing booth with D-50 fluorescent light source located at Sensi Complex of Center for Imaging Science of R.I.T. was used to provide a standard illumination for the subjective visual evaluation of sample proofs.

The viewing distance for observers was within thirty to forty centimeters. The observers were asked to observe the overall color hue shift, sharpness, and detail of the proofs. The observers were not allowed to touch the proofs or permitted to change their ratings. Scratches, dirt spots, and the surface reflection on the proofs were to be ignored. The subjective visual evaluation was based upon the observers' overall impression, satisfaction, and preference, and performed by the category analysis.

4.Data Collection

For the method of category analysis, data were collected by a rating scale. A rating form was used to retain the use of the term scale for the results of applying a formal scaling model. A rating form was a set of categories by which a subject was required to partition a set of stimuli into mutually exclusive classes (Ref.24).

In this method, sample proof was presented randomly to the observer one at a time. Then the observer was asked to choose a rating which best represents his preference in color performance, sharpness, and detail for the proof. A rating form was defined and provided as follows:

1 excellent
2 very good
3 good
4 acceptable
5 unsatisfactory
6 poor
7 unusable

Three precisely registered conventional chromatic separation proofs were presented as rating one to the observers, so they could have a point to start with. Fifty seven proofs were viewed and given ratings by thirty observers. After that, three precisely registered GCR separation proofs were assigned as rating one by all the

observers. Totally, fifty four sample proof rating data were analyzed by the method of category.

All thirty observers made their evaluation in a single session lasting about thirty minutes. During this period of time, the observers were asked to perform as consistent as possible.

5.Category Analysis

Each proof had thirty observers's preferred ratings (categories) from one to seven. The frequency of ratings were obtained by adding up all the number of observers in each rating (category) for every proof. Then the frequency of ratings were transformed into cumulative proportions, P_{jk}, of ratings for each proof, as in table 1. From a table of the normal probability distribution, these proportions, P_{jk}, were transformed into normal deviates, Y_{jk}; in table 2 appear the Y_{jk} corresponding to the P_{jk} of table 1.

When the values of cumulative proportions more extreme than .01 or .99, the sampling of variance of normal deviate is intolerably large. For this reason, in Table 2, a Y_{jk} value was estimated when the corresponding P_{jk} value in table 1 was larger than .99 or less than .01.

The estimation was proceeded as follows. The mean difference between the existed Yjk in two adjacent columns of table 2 was found, based upon only those rows of a table in which a Yjk value was recorded in each of the two columns. This mean difference then was taken as the expected increment in Yjk values in those cases where no entry existed. These estimates were recorded in parentheses in the appropriate cells.

In the same procedure, estimates were obtained for the missing Yjk. Adding the mean difference between two adjacent columns to the estimates in parentheses, column n, yielded the estimates in parentheses, column n-1. Subtracting the mean difference to the estimates in parentheses, column n, yielded the estimates in parentheses, column n+1.

The boundaries of categories were determined by adding all the normal deviates, Yjk, together in each column and dividing by fifty four. Then shifted the boundary scale by adding the average of two boundaries, column 3 and column 4, to each boundary. The fourth category of the rating form was named " acceptable," neither like nor dislike, a neutral category. The midpoint of the fourth category, equidistant from the upper bound of category 3 and the upper bound of category 4, was the average of these two boundaries. Now, the boundary scale origin is at the point of neutrality or indifference of judgment.

The cumulative proportions were plotted against the shifted boundaries on normal probability paper. A straight line was drawn so as to minimize approximately the vertical discrepancies, in proportion units, of points from the line. The intercept of the line of the best fit with the value P=.50 provided an estimate for the mean of boundary scale of a proof. Therefore, each proof had a boundary scale value, boundary mean, to represent its image quality in the method of category.

6.SQF and Boundary Scale

To apply SQF value to sample proofs, subjective visual evaluation was performed in this stage of study. Eighteen out of fifty four misregistered proofs with approximately even distance of scale value to each other and six precisely registered proofs were evaluated against the standard SQF photographic images. The image quality of those proofs on the SQF scale were determined subjectively.

Those boundary mean values and SQF values of eighteen misregistered proofs were analyzed by the method of linear regression. This method provided a close approximation and the best possible fit to the data points. The SAS software package in VAX/VMS was used to do the regression analysis. Then three regression equations were performed to express the relationship between boundary scale value and SQF value for three different images. By the use of proper regression

equations, all the boundary means were transformed into corresponding SQF values. The SQF value of a proof is the output image quality of the original.

The SQF values were plotted versus the misregistration magnitudes for each color separation method and image. Six plots were obtained, each of them containing three color inks's performance in misregistration. Using five units of SQF value as JND, the relationship between two different color separation methods was investigated, and the misregistration tolerance limits were determined.

ChapterV. EXPERIMENTAL RESULTS

Three regression equations showing the linear relationship between boundary value and SQF value are on figure eleven, twelve, and thirteen. For image A, the median frequency image, is Y=78.0-2.99*X with a 96.9% R-square. Image B, the low frequency image, is Y=78.2-2.89*X with a 99.1% R-square. Image C, the high frequency image, is Y=77.1-1.22*X with a 90.7% R-square.

Table three contains the misregistration magnitudes, boundary mean values, and corresponding SQF values for each sample proofs. The plots of SQF value versus misregistration magnitude are on figure fourteen, fifteen, sixteen, seventeen, eighteen, and nineteen. There are three lines in each plot with square, circle, and triangle symbols. The square symbol represented the yellow ink, the circle symbol represented the magenta ink, and the triangle symbol represented the cyan ink.

The image quality of proofs of the same original within 0.0 and 0.1mm magnitudes had the same SQF value. The yellow ink had the best performance in all misregistration magnitude of three images for both separation methods. In image A, the yellow ink had less than one SQF difference between two separation methods on 0.2, 0.3, and 0.4 mm magnitudes. And, the yellow ink performed the same in image

B and C, all the SQF difference between two separation methods was less than one on those magnitudes.

The magenta ink had the worst performance in each image from the magnitude 0.2mm to 0.4mm. Excepting in image A conventional chromatic separation with 0.4mm magnitude, and GCR separation with 0.2 mm magnitude, it had performed the same (same SQF value) with the cyan ink. The magenta ink was carried out differently by a range of 1.5 to 2.6 SQF values in those two separation methods of image A. Same distance, but shifted by 0.3 units, it was 1.2 to 2.3 SQF values in image B. In image C, the difference was close, 0.7 SQF values, on 0.2 and 0.3mm. But, it became 4.6 SQF values on the magnitude of 0.4mm.

The SQF value difference of two separation methods was from 1.0 to 4.1 in image A for cyan ink. And it was shifted by 0.7 SQF units, 0.3 to 3.4, in image B. In image C, the difference was less than one and half SQF value.

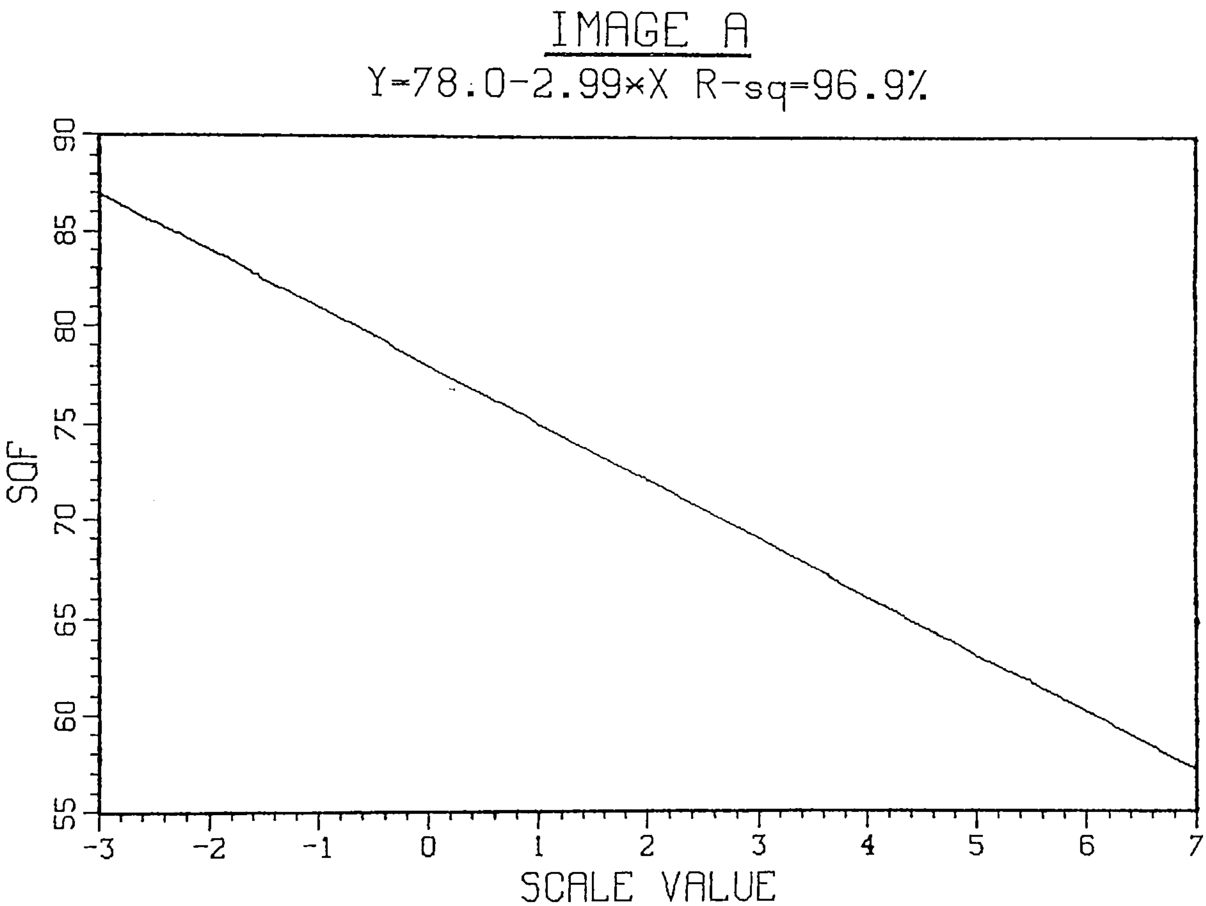


IMAGE A
Y=78.0-2.99*X R-sq=96.9%
90
85
80
75
70
65
60
55
SQF
-3
-2
-1
0
1
2
3
4
5
6
7
SCALE VALUE

Figure 9.

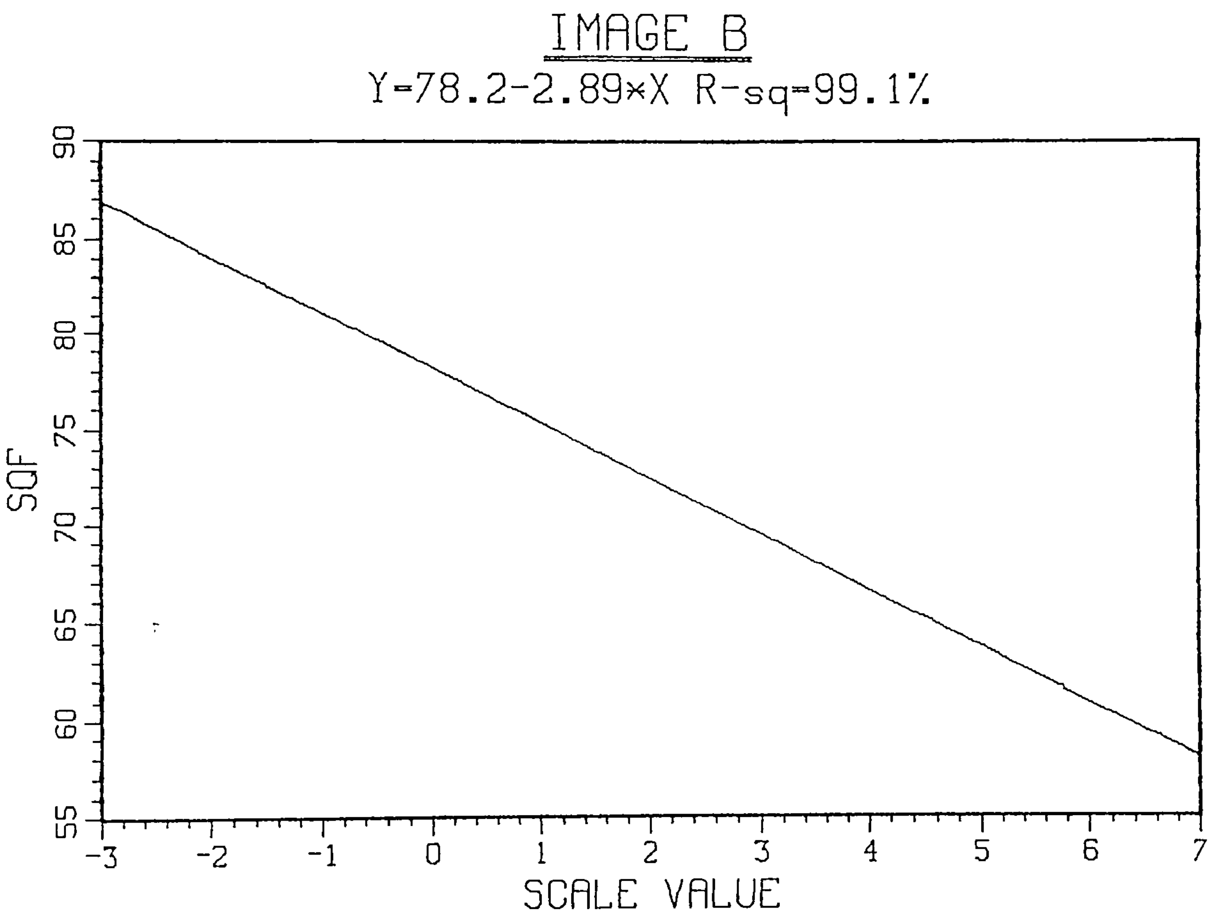


IMAGE B
Y=78.2-2.89*X R-sq=99.1%
SQF
90
85
80
75
70
65
60
55
-3
-2
-1
0
1
2
3
4
5
6
7
SCALE VALUE

Figure 10.

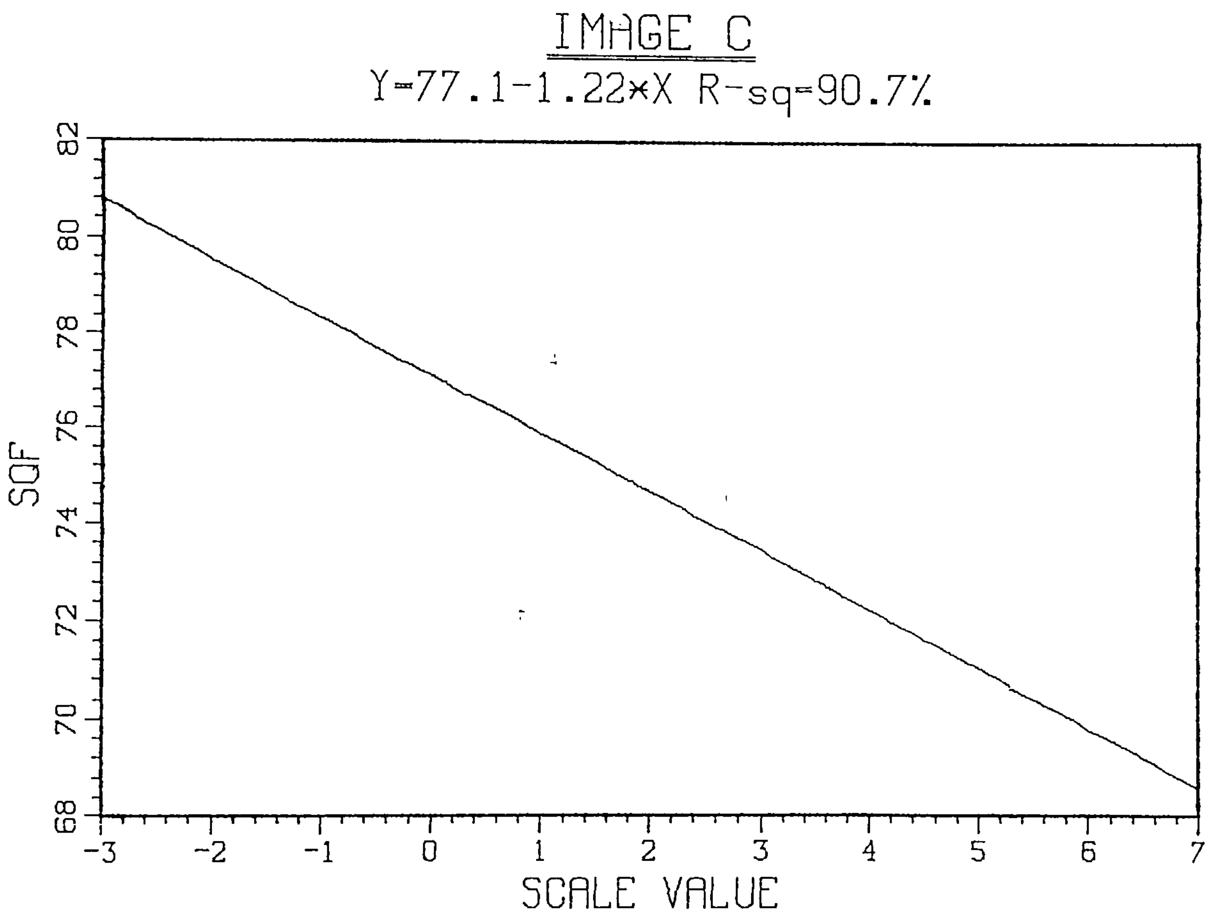
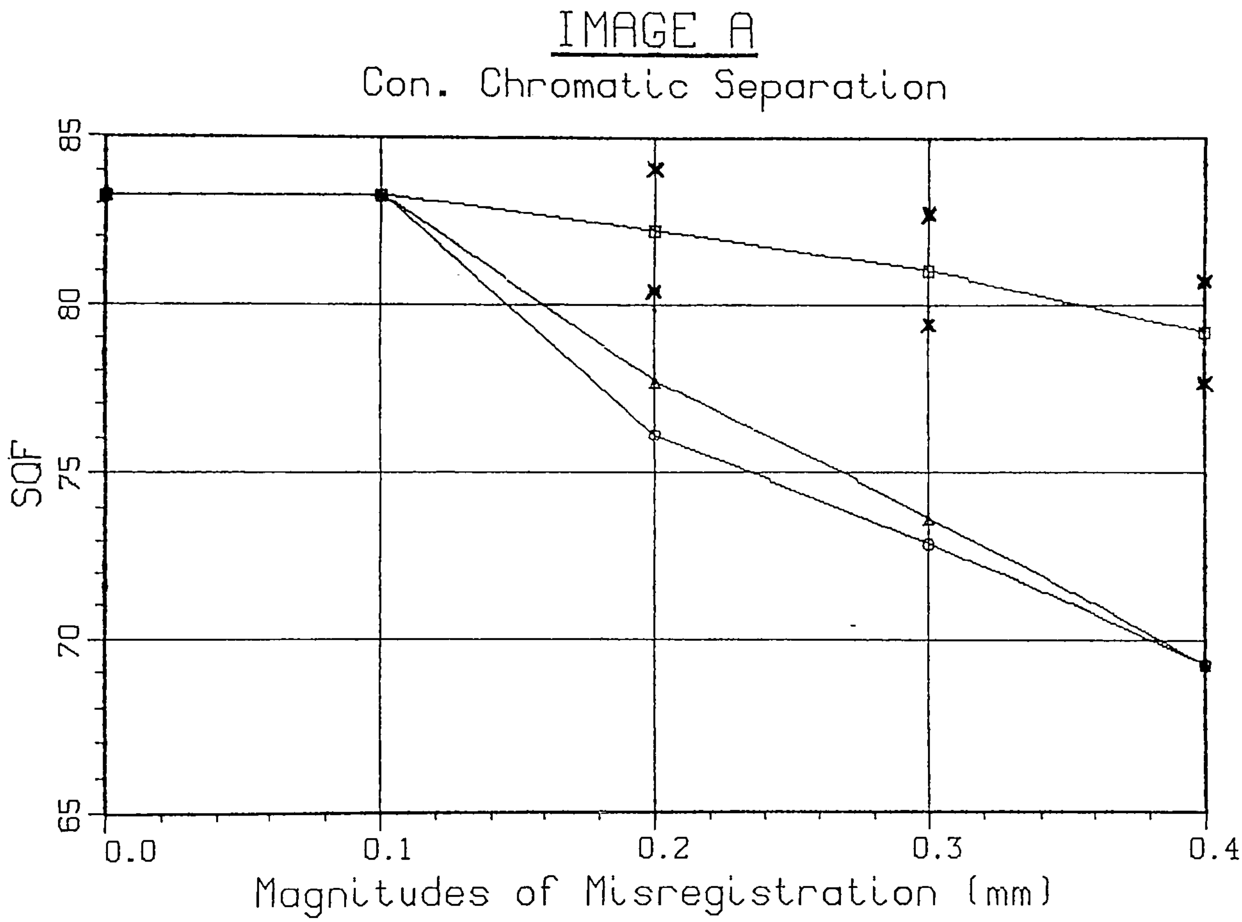


IMAGE C
Y=77.1-1.22*X R-sq=90.7%
SQF
82
80
78
76
74
72
70
68
-3
-2
-1
0
1
2
3
4
5
6
7
SCALE VALUE

Figure 11.



x INDICATES THE 95% CONFIDENCE INTERVAL FOR YELLOW

Figure 12.

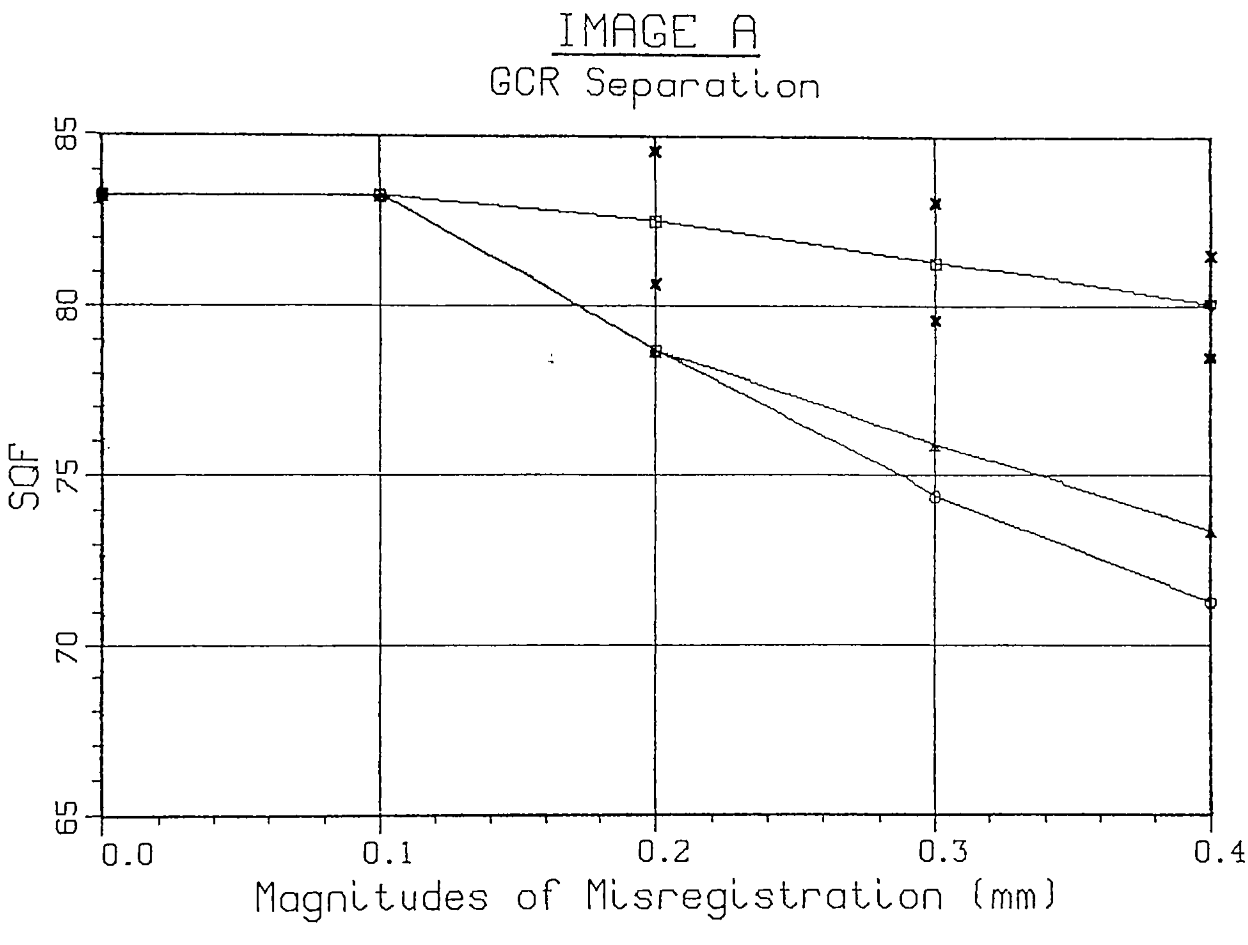


IMAGE A
GCR Separation
85
80
75
70
65
SQF
0.0
0.1
0.2
0.3
0.4
Magnitudes of Misregistration (mm)

Figure 13.

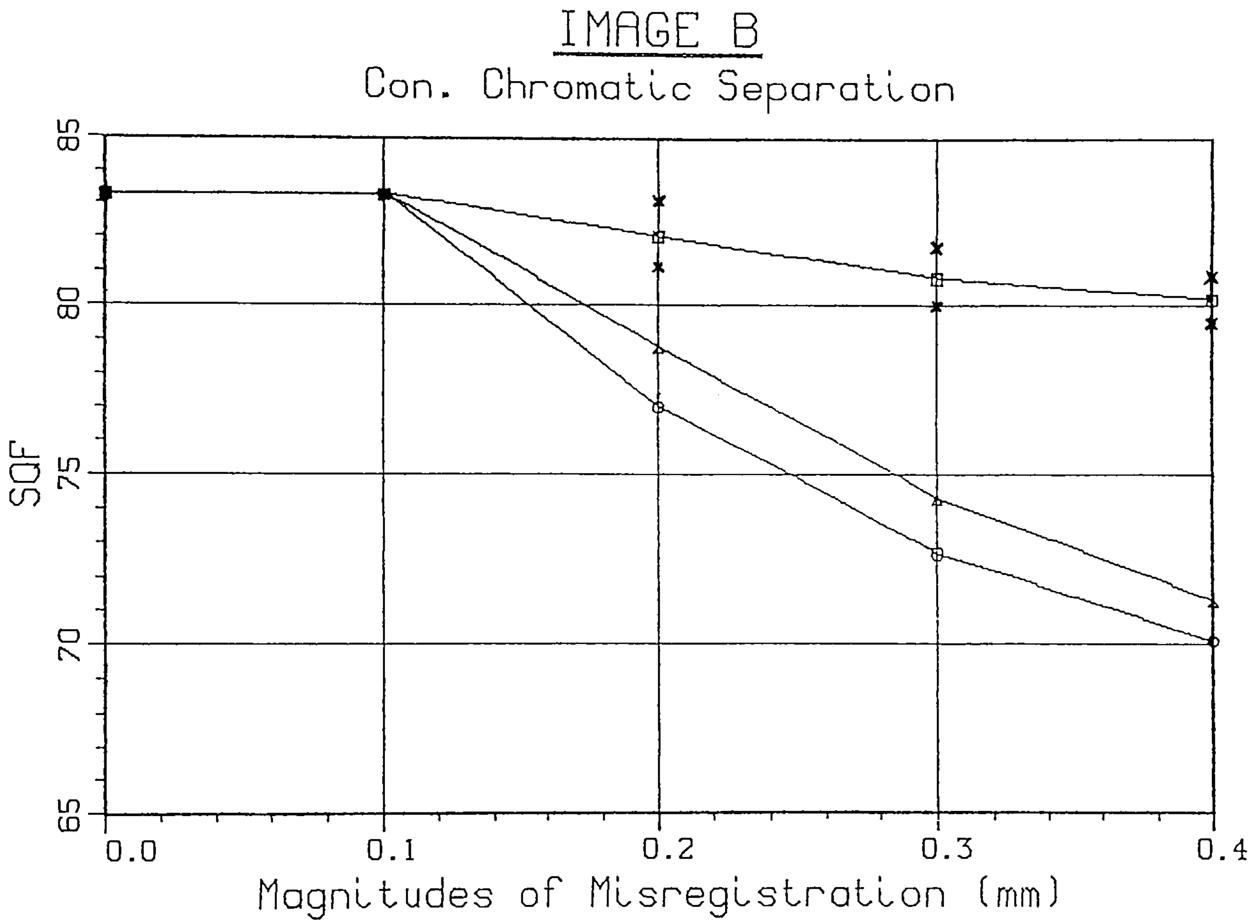


IMAGE B
Con. Chromatic Separation
85
80
75
70
65
SQF
0.0
0.1
0.2
0.3
0.4
Magnitudes of Misregistration (mm)

Figure 14.

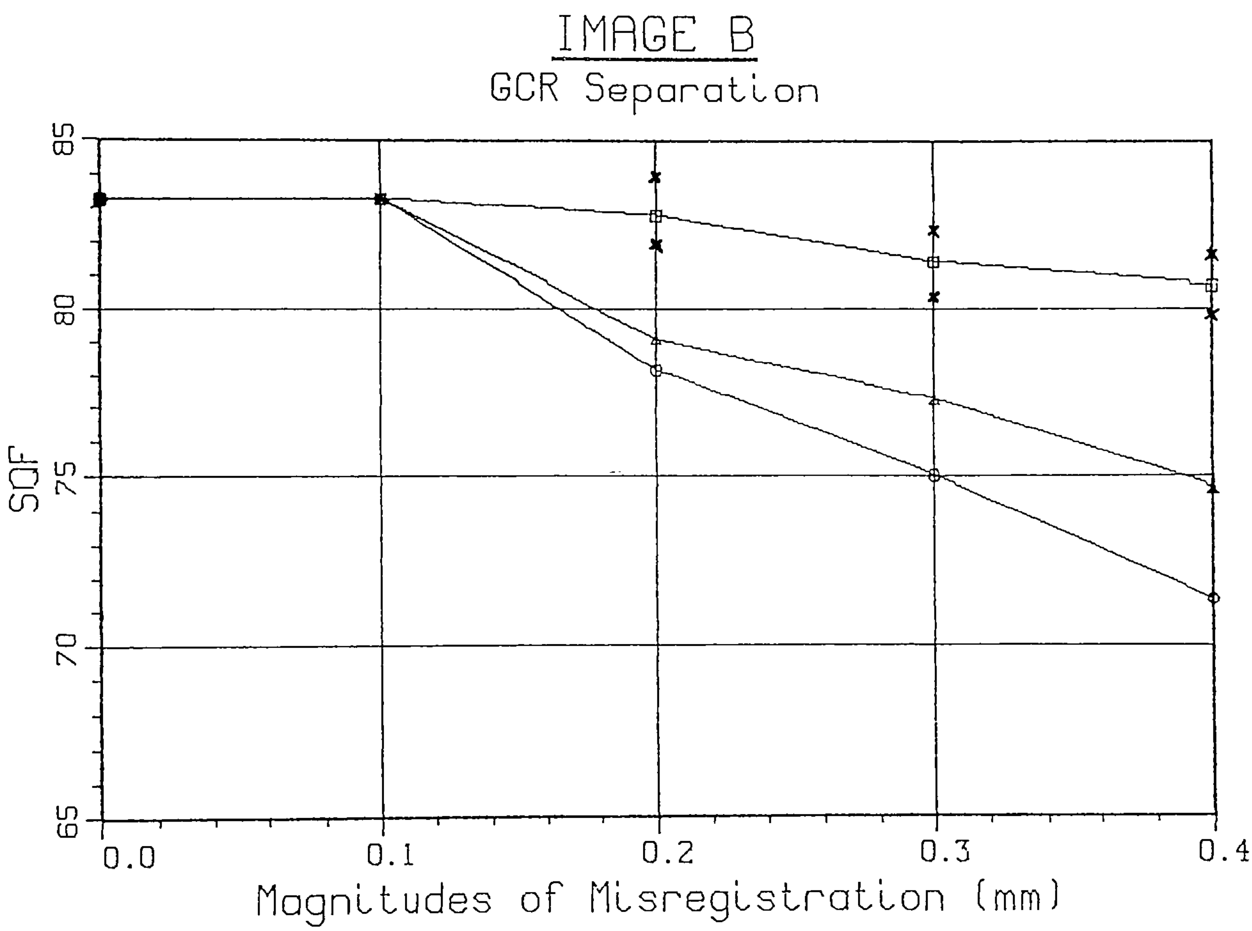


IMAGE B
GCR Separation
SQF
85
80
75
70
65
0.0
0.1
0.2
0.3
0.4
Magnitudes of Misregistration (mm)

Figure 15.

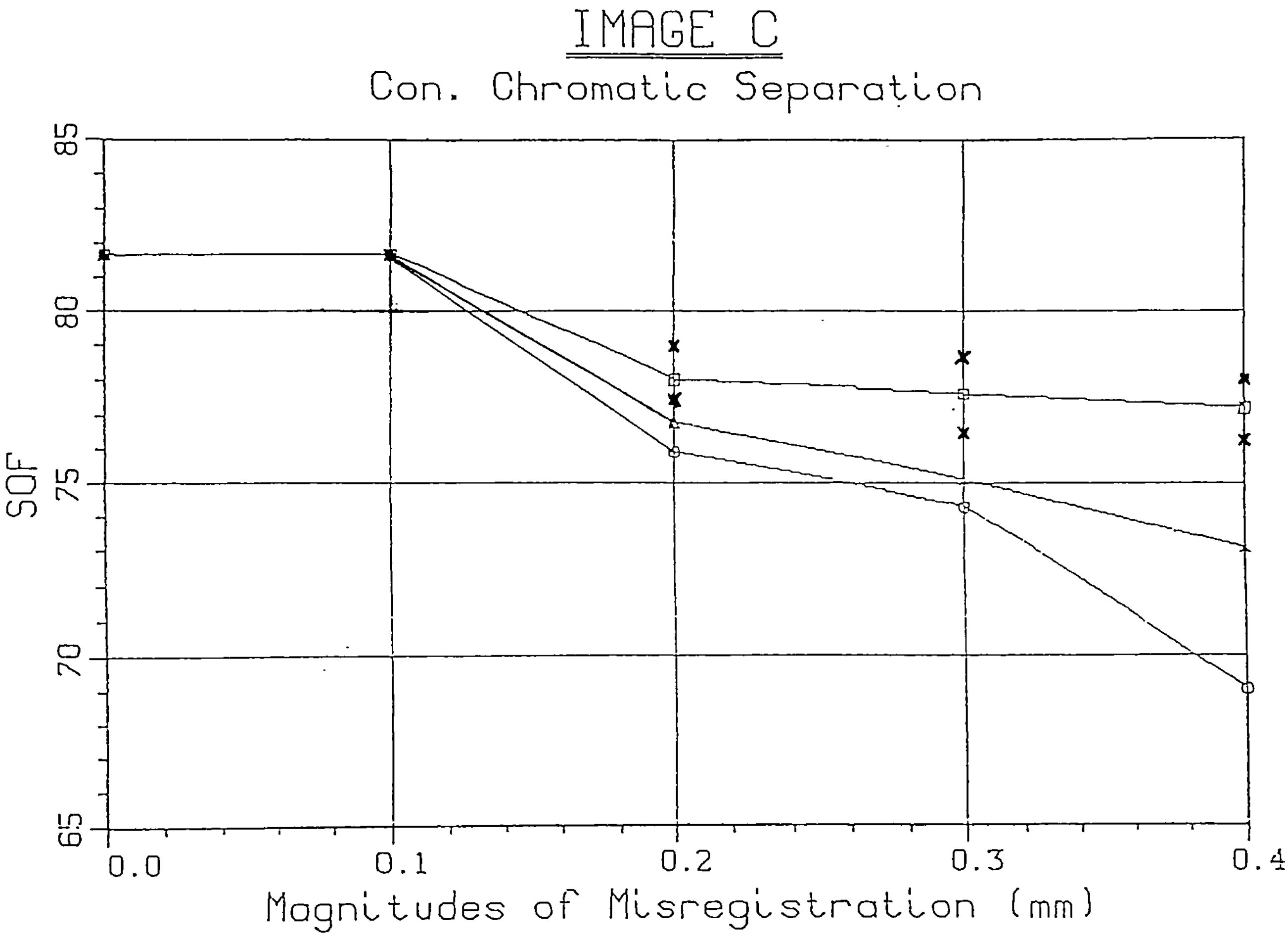


IMAGE C
Con. Chromatic Separation
SQF
85
80
75
70
65
0.0
0.1
0.2
0.3
0.4
Magnitudes of Misregistration (mm)

Figure 16.

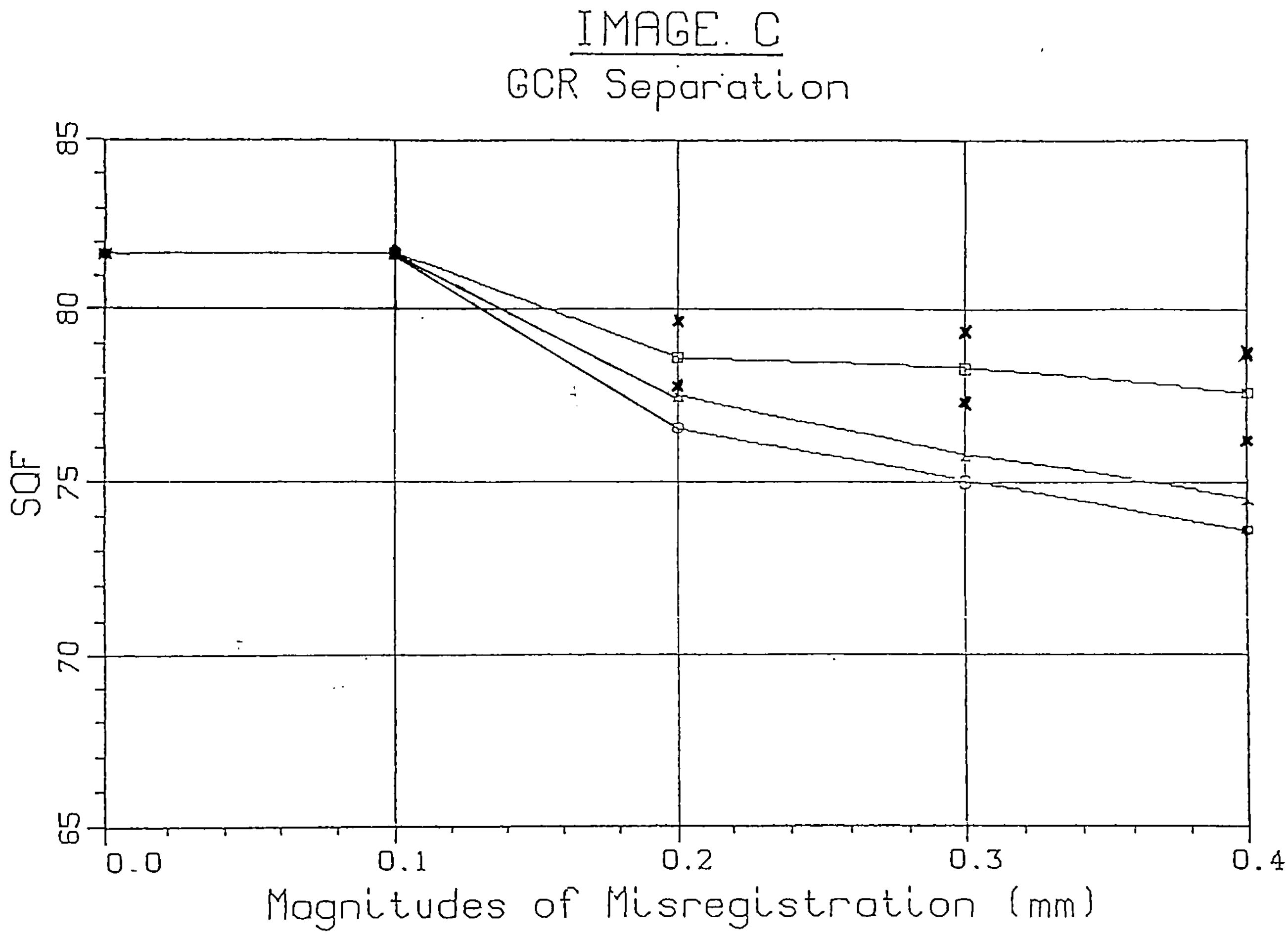


IMAGE C
GCR Separation
SQF
85
80
75
70
65
0.0
0.1
0.2
0.3
0.4
Magnitudes of Misregistration (mm)

Figure 17.

ChapterVI. DISCUSSION

As discussed in chapter four section two, an off-press proofing system, 3M MatchprintII, was used. It provided an easier way to control the tone reproduction, eliminated the other variables which usually happened in multicolor halftone printing. Therefore, the image quality difference between sample proofs was only the result of the misregistration and separation methods.

In general, GCR proofs had higher SQF values than conventional chromatic proofs in the magnitudes from 0.2 to 0.4mm. Especially, the cyan ink misregistered proofs in image A and B of a magnitude of 0.4mm, and the magenta ink in image C with 0.4mm magnitude.

1. The Median Frequency Image (Image A)

This image contained a female model wearing a cream color sweater and a pair of white trousers. The whole scene had a light white background. The SQF value is 83.2 for the magnitude equal to and less than 0.1mm in GCR and conventional chromatic proofs.

In the yellow ink, all the misregistered proofs are acceptable. The differences between precisely registered and misregistered proofs are less than the JND value, five

SQF units. The highest difference value is 4.0 on SQF scale of a 0.4mm magnitude on conventional chromatic proof. Then, it reduced to 3.1 on GCR proof. These two proofs viewed the same to the precisely registered one. The image quality difference is not noticeable.

In the magenta ink, the GCR proof with a 0.2mm magnitude is the only acceptable one of six proofs from 0.2 to 0.4mm. The conventional chromatic proof's image quality is 76.1 on SQF scale of this magnitude. The GCR proof is 78.7. The image quality difference between this GCR proof and precisely registered proof is 4.5 SQF units. It is less than the JND value. All the other proofs have bigger difference values than the JND. The GCR proofs do have higher SQF values which mean the difference values are smaller. But, the image quality is still not close to that of the precisely registered proofs.

In the cyan ink, the only proof's image quality within the JND range is the one with a magnitude of 0.2mm in GCR method. Two proofs in this magnitude are 77.7 SQF values for conventional chromatic one, and 78.7 for the GCR one. The SQF values of other proofs are far from 83.2, the differences are in a range of 7.3 to 13.9. In the 0.4mm magnitude, the GCR proof has a 4.1 units higher SQF value than the conventional chromatic proof. It is the biggest image quality difference between these two separation methods in this image.

2. The Low Frequency Image (Image B)

Two tomatoes, one with a red color, the other painted with white color, were the objects of this image. There were no complicated details and fine lines, just simple lines and uniform color on this image. Eighty percent of the background was dark color. The image quality of the proof with a magnitude under or equal to 0.1mm is 83.2 in terms of SQF.

In the yellow ink, all the proof's image quality SQF values are less than 83.2 in the magnitude of 0.2 to 0.4mm. But, the differences are no more than the JND value. Therefore, every misregistered proof is viewed no apparent difference with the precisely registered one.

In the magenta ink, there is not any proof's image quality acceptable in the magnitude of 0.2 to 0.4mm. All the SQF value differences between misregistered and precisely registered proofs are bigger than or equal to the JND value. These two groups of proof are viewed noticeable different from each other.

In the cyan ink, the image quality of two proofs with a magnitude of 0.2mm is within the acceptable range. The SQF value differences between them and the precisely registered proofs are less than the JND value. The other proofs with the magnitudes of 0.3 and 0.4mm, are viewed noticeable

different from the precisely registered proofs. The biggest SQF difference between two separation methods is 3.4 units. This is in the magnitude of 0.4mm.

3. The High Frequency Image (Image C)

A lounge hall with green plants and black steel framed glass ceiling was the main scene of this image. It contained many fine details of the plants and the framed ceiling. Through the glass ceiling, blue sky was part of the background. The image quality of the proofs less than or equal to 0.1mm is 81.8 SQF value.

In the yellow ink, the situation was the same, all the misregistered proofs are acceptable. The SQF value differences between these proofs and precisely registered proofs are from 3.2 to 4.6 SQF units. As the definition of JND, these proofs appeared no difference to human eye.

In the magenta ink, all the proofs in the magnitudes of 0.2 to 0.4mm are viewed different from the one without misregistration. These proofs have higher SQF value differences than the JND from 5.2 to 12.8 SQF units. The biggest difference between two separation methods in this image happened on 0.4mm magnitude. It is 4.6 SQF units. This is also the highest separation method difference found in this study.

In the cyan ink, only one misregistered proof's SQF difference with the precisely registered proof is within the JND range. This is the GCR proof with a 77.5 SQF value in 0.2mm magnitude. The other proofs from 0.2 to 0.4mm magnitudes are in the range of 73.1 to 76.8.

4. Color Ink Performance

As a rule of thumb, yellow is the least sensitive color to the human eye in the subtractive process, multicolor halftone printing. It had been proved true again. The yellow ink had the best performance in this study. When the yellow ink was out of registration to 0.4mm, two dots, it is still not objectionable. The highest SQF value difference between yellow ink misregistered proofs and the proofs without misregistration is 4.6. This is the image C conventional chromatic proof in the magnitude of 0.4mm. Since this difference is less than the JND value, the image quality of this proof still acceptable.

The image quality of magenta ink misregistered proof was the worst in three images. The lowest SQF value, 69.0, was found in this group. It was the conventional chromatic proof of image C in 0.4mm magnitude. In all proofs of the magnitude from 0.2 to 0.4mm, only the GCR one with a magnitude of 0.2mm is acceptable. And the SQF value of this proof is 78.7 even lower than the worst one, 79.2, in the yellow ink misregistered proof.

The cyan ink performance was better than magenta, but not much. Three GCR and one conventional chromatic proof were acceptable. These are with the same 0.2mm magnitude. The SQF value differences between these proofs and the precisely registered proofs are from 4.1 to 4.5.

5. The Image Quality of GCR Technique

Every GCR proof did have a higher SQF value than the corresponding conventional chromatic proof. But, people can not tell the image quality distinction between GCR proof and conventional chromatic proof, in yellow ink misregistration. The differences of SQF values between them were small, less than one unit.

In the magenta ink, the GCR technique improved the quality of proof became acceptable in 0.2mm magnitude of image A. In the cyan ink, it improved the proof's image quality in 0.2mm magnitude for image A and C. For all the other conventional chromatic proofs, the GCR method did improve the image quality of them, increasing the SQF values; but that was not enough to make these proofs to become acceptable. Two conventional chromatic proofs in image A and C with a magnitude of 0.4mm, the GCR method increased the SQF values of them by 4.1 and 4.6 units. But, the GCR proofs still had 9.8 and 8.2 differences with the SQF values of precisely registered proofs. These differences are 4.8 and 3.2 units higher than the JND value.

ChapterVII. CONCLUSION

Theoretically, the GCR technique can produce sharper looking images. Most of the detail and shape is provided by the black printer, making exact registration no longer required to provide the sharpness of the reproduction in multicolor halftone printing. Based on this study, this statement is true for the reproductions of median frequency images equal to 0.2mm misregistration magnitude in magenta and cyan inks, for the reproductions of low and high frequency images equal to 0.2mm magnitude in cyan ink.

The yellow ink is the least sensitive ink to the human eye. It did not make any difference by using the GCR method in yellow misregistration reproduction. All the SQF values of conventional chromatic and GCR reproductions were close, the differences between them were less than one SQF unit. The magenta ink had the most impact in misregistration of both conventional chromatic and GCR reproductions.

Based on the data from this study, the image quality of GCR proof seems to appear slightly improvement. But, the improvement is not significant to state that the GCR is an outstanding technique in misregistration performance. The image quality of a proof improved by the GCR technique was only a difference between 0.3 and 4.6 SQF units. It had to be as great as difference of five SQF units to be significant.

From the average SQF value for each color ink in three images, there is no significant difference between these two color separation techniques. The differences between proofs in three color ink were less than five SQF units. They were between 0.6 to 2.4 SQF units.

From the results of this study, the yellow ink had the same misregistration tolerance limits, 0.4mm, in both conventional chromatic and the GCR techniques for three images, in 65 line/inch screen ruling multicolor halftone printing. For the magenta ink, the tolerance limits was 0.2mm in median frequency image and 0.1mm for low and high frequency images using the GCR technique. And it was 0.2mm for cyan ink in three images.

The experimental results also indicated that the reproductions of the high frequency image had lower SQF values than the reproductions of low and median frequency images. In order to reproduce the same image quality, more precise registration in high frequency image is required.

ChapterVIII. SUGGESTION FOR FUTURE WORK

Many parameters, such as: solid ink density, dot gain, and paper quality, will affect the final image quality of a reproduction in multicolor halftone printing. But, a off-press proofing system, 3M Matchprint, was used in this study. It provided good control of those parameters. Therefore, the effect of misregistration in conventional chromatic and GCR separation methods can be studied without being influenced by those factors.

Screen ruling is also an important factor of the image quality of reproduction. Within 65 and 150 line/inch screen rulings, the finer the screen ruling, the better the image quality. The coarsest screen ruling, 65 line/inch, using in printing industry was chosen in this study. The image quality of reproduction produced by the use of this screen ruling is not as good as the original's, in terms of sharpness and detail expression. It allowed to have more misregistration magnitude tolerances.

In the printing industry, fifty to sixty percent of GCR is using when making the GCR separation. It is useful to know how does the black ink perform in misregistration using lower percentage of GCR. So, in the future study, an offset press, a finer screen ruling, a lower percentage of GCR, and a black ink misregistration should be used to repeat the experiment procedure. Then four color ink performance in

press with a finer screen ruling and a lower GCR percentage can be evaluated.

VIII.REFERENCES

1. J.A.C. Yule,"Color Correction and the Black Printer", TAGA, (1949)

2. H. Takeuchi and T. Imamoto,"Automatic Presetting System of Registration on an Offset Printing Press", TAGA, 428, (1984)

3. H. Takeuchi and T. Imamoto, TAGA, 429, (1984)

4. J. Anon,"Pin Registration Systems Make Mounting Large Plates a Snap", FlexoTech.J. Vol.10, No.12, 28, Dec. (1985)

5. M.R.Wilson,"Machine Vision in the Graphic Arts: Digital Registration of Four Color Halftone Separations", TAGA, 525, (1986)

6. J. Chen,"An Investigation of Color Variation as a Function of Register in Dot-on-Dot Multicolor Halftone Printing", TAGA, 315, (1985)

7. J. Chen, TAGA, 525, (1985)

8. J.A.C. Yule,"Principles of Color Reproduction", John Wiley and Sons, New York, 335, (1967)

9. J.A.C. Yule,"The Theory of Subtractive Color Photography; III, Four Color Processes and the Black Printer" J.Opt.Soc.Am.,Vol.30, 322, (1949)

10. P.E. Tobias, TAGA, 85, (1954)

11. A.G.Saleh,"Investigation into the Application of Achromatic Synthesis to the Printing Industry", TAGA, 152, 155, (1986)

12. J. Stockton,"Designer's Guide to Color", 55 (1984)

13. J. Stockton, 33 (1984)

14. J. Stockton, 35 (1984)

15. J.L. Noga, personal communication, (1988)

16. B.A. Frost,"The Grey Component Replacement-a New Trend in Color Reproduction",TAGA, 399, (1986)

17. E.M.Granger,"Specification of Color Image Quality", Institute of Optics Ph.D. dissertation, University of Rochester, N.Y., June, (1974)

18. Ibid.,P.5.

19. O.H. Schade, J.S.M.P.T.E. 73, 81, (1964)

20. E.M.Granger and K.N. Cupery, Photogr.Sci.Eng. 16, 221, (1972)

21. E.M.Granger,"Subjective Assessment and Specification of Color Image Quality", SPIE, May (1974)

22. E.M.Granger, personal communication, (1987)

23. L.A.Dvorak, and J.R.Hamerly,"Just-Noticeable Difference for for Text Quality Components", J.A.P.E.,9, (3), 97, (1983)

24. R.D.Bock, and L.V.Jones,"The Measurement and Prediction of Judgment and Choice", 1968

Table 1. Cumulative Proportions, Pjk, of Ratings over Seven Categories for Fifty Seven Sample Proofs

	Category						
Image	1	2	3	4	5	6	7
CAY 1	.300	.800	1.000	1.000	1.000	1.000	1.000
CAY 2	.167	.633	1.000	1.000	1.000	1.000	1.000
CAY 3	.067	.333	.833	1.000	1.000	1.000	1.000
CBY 1	.300	.733	1.000	1.000	1.000	1.000	1.000
CBY 2	.133	.600	.933	1.000	1.000	1.000	1.000
CBY 3	.167	.400	.900	1.000	1.000	1.000	1.000
CCY 1	.167	.500	1.000	1.000	1.000	1.000	1.000
CCY 2	.067	.367	.833	1.000	1.000	1.000	1.000
CCY 3	.067	.200	.467	.967	1.000	1.000	1.000
GAY 1	.333	.833	1.000	1.000	1.000	1.000	1.000
GAY 2	.200	.767	.967	1.000	1.000	1.000	1.000
GAY 3	.167	.467	.900	.967	1.000	1.000	1.000
GBY 1	.400	.867	1.000	1.000	1.000	1.000	1.000
GBY 2	.200	.733	.967	1.000	1.000	1.000	1.000
GBY 3	.267	.567	.934	1.000	1.000	1.000	1.000
GCY 1	.267	.733	.967	1.000	1.000	1.000	1.000
GCY 2	.267	.467	.967	1.000	1.000	1.000	1.000
GCY 3	.133	.400	.733	1.000	1.000	1.000	1.000

Table 1. Continued

Image	Category 1	2	3	4	5	6	7
CAM 1	.000	.200	.433	.700	1.000	1.000	1.000
CAM 2	.000	.033	.100	.400	.667	1.000	1.000
CAM 3	.000	.000	.033	.066	.300	.633	1.000
CBM 1	.000	.067	.433	.933	1.000	1.000	1.000
CBM 2	.000	.000	.033	.333	.667	1.000	1.000
CBM 3	.000	.000	.000	.100	.367	.667	1.000
CCM 1	.000	.100	.200	.567	.933	1.000	1.000
CCM 2	.000	.000	.067	.100	.300	.933	1.000
CCM 3	.000	.000	.000	.067	.100	.167	1.000
GAM 1	.000	.333	.733	1.000	1.000	1.000	1.000
GAM 2	.000	.033	.200	.600	.867	1.000	1.000
GAM 3	.000	.000	.067	.234	.500	.833	1.000
GBM 1	.000	.200	.733	.933	1.000	1.000	1.000
GBM 2	.000	.067	.200	.533	.900	1.000	1.000
GBM 3	.000	.000	.000	.200	.467	.800	1.000
GCM 1	.033	.133	.367	.833	1.000	1.000	1.000
GCM 2	.000	.000	.133	.267	.733	1.000	1.000
GCM 3	.000	.000	.000	.100	.233	.700	1.000

Table 1. Continued

Category

Image	1	2	3	4	5	6	7
CAC 1	.000	.167	.734	.934	1.000	1.000	1.000
CAC 2	.000	.033	.100	.467	.800	1.000	1.000
CAC 3	.000	.000	.033	.133	.300	.667	1.000
CBC 1	.067	.167	.767	.967	1.000	1.000	1.000
CBC 2	.000	.000	.133	.467	.900	1.000	1.000
CBC 3	.000	.000	.033	.133	.400	.833	1.000
CCC 1	.000	.200	.467	.900	1.000	1.000	1.000
CCC 2	.000	.000	.167	.300	.767	.967	1.000
CCC 3	.000	.000	.000	.100	.200	.500	1.000
GAC 1	.067	.467	.733	.933	1.000	1.000	1.000
GAC 2	.000	.067	.367	.733	.967	1.000	1.000
GAC 3	.000	.033	.100	.433	.800	.933	1.000
GBC 1	.033	.333	.800	1.000	1.000	1.000	1.000
GBC 2	.000	.133	.467	.933	1.000	1.000	1.000
GBC 3	.000	.033	.133	.467	.933	1.000	1.000
GCC 1	.100	.300	.733	.933	1.000	1.000	1.000
GCC 2	.000	.033	.200	.633	1.000	1.000	1.000
GCC 3	.000	.000	.067	.200	.400	.933	1.000

Table 2. Normal Deviates, Yjk, Associated with the Pjk of Table 1.

Image	Category 1	2	3	4	5	6
CAY 1	- .522	.842	(1.915)	(2.884)	(3.790)	(4.840)
CAY 2	- .966	.340	(1.413)	(2.382)	(3.290)	(4.340)
CAY 3	-1.499	- .432	.966	(1.936)	(2.846)	(3.895)
CBY 1	- .524	.622	(1.695)	(2.664)	(3.574)	(4.623)
CBY 2	-1.112	.253	1.499	(2.468)	(3.378)	(4.427)
CBY 3	- .966	- .253	1.282	(2.251)	(3.160)	(4.210)
CCY 1	- .966	.000	(1.073)	(2.042)	(2.952)	(4.000)
CCY 2	-1.499	- .340	.966	(1.936)	(2.846)	(3.895)
CCY 3	-1.499	- .842	- .083	1.838	(2.749)	(3.798)
GAY 1	- .432	.966	(2.039)	(3.008)	(3.918)	(4.967)
GAY 2	- .842	.729	1.838	(2.808)	(3.718)	(4.767)
GAY 3	- .966	- .083	1.282	1.838	(2.749)	(3.798)
GBY 1	- .253	1.112	(2.186)	(3.155)	(4.065)	(5.114)
GBY 2	- .842	.622	1.838	(2.808)	(3.718)	(4.767)
GBY 3	- .622	.169	1.506	(2.476)	(3.386)	(4.435)
GCY 1	- .622	.622	1.838	(2.808)	(3.718)	(4.767)
GCY 2	- .622	- .083	1.838	(2.808)	(3.718)	(4.767)
GCY 3	-1.112	- .253	.622	(1.591)	(2.501)	(3.550)

Table 2. Continued

Category

Image	1	2	3	4	5	6
CAM 1	(-1.915)	- .842	- .169	.524	(1.435)	(2.484)
CAM 2	(-2.912)	-1.838	-1.282	- .253	.432	(1.481)
CAM 3	(-3.986)	(-2.912)	-1.838	-1.506	- .524	.340
CBM 1	(-2.572)	-1.499	- .169	1.499	(2.409)	(3.458)
CBM 2	(-3.986)	(-2.912)	-1.838	- .432	.432	(1.481)
CBM 3	(-4.400)	(-3.324)	(-2.250)	-1.282	- .340	.421
CCM 1	(-2.355)	-1.282	- .842	.169	1.499	(2.548)
CCM 2	(-3.646)	(-2.572)	-1.499	-1.282	- .524	1.499
CCM 3	(-4.615)	(-3.541)	(-2.470)	-1.499	-1.282	- .966
GAM 1	(-1.505)	- .432	.622	(1.591)	(2.501)	(3.550)
GAM 2	(-2.912)	-1.838	- .842	.253	1.112	(2.162)
GAM 3	(-3.646)	(-2.572)	-1.499	- .726	0.000	.966
GBM 1	(-1.915)	- .842	.622	1.499	(2.409)	(3.458)
GBM 2	(-2.572)	-1.499	- .842	.083	1.282	(2.331)
GBM 3	(-3.960)	(-2.880)	(-1.810)	- .842	- .083	.842
GCM 1	-1.838	-1.112	- .340	.966	(1.877)	(2.926)
GCM 2	(-3.260)	(-2.190)	-1.1123	- .6219	.6219	(1.671)
GCM 3	(-4.398)	(-3.324)	(-2.250)	-1.2816	- .729	.5244

Table 2. Continued

	Category					
IMAGE	1	2	3	4	5	6
CAC 1	(-2.040)	- .9661	.625	1.5063	(2.417)	(3.466)
CAC 2	(-2.912)	-1.8384	-1.2816	- .0828	.8416	(1.891)
CAC 3	(-3.986)	(-2.912)	-1.8384	-1.1123	- .5244	.4316
CBC 1	-1.4985	- .9661	.729	1.8384	(2.749)	(3.798)
CBC 2	(-3.260)	(-2.186)	-1.1123	- .0828	1.2816	(2.331)
CBC 3	(-3.986)	(-2.912)	-1.8384	-1.1123	- .2533	.9661
CCC 1	(-1.915)	- .8416	- .0828	1.2816	(2.192)	(3.241)
CCC 2	(-3.110)	(-2.040)	- .9661	- .5244	.729	1.8384
CCC 3	(-4.400)	(-3.324)	(-2.250)	-1.2816	- .8416	0.0000
GAC 1	-1.4985	- .0828	.6219	1.4985	(2.409)	(3.458)
GAC 2	(-2.572)	-1.4985	- .3398	.6219	1.8384	(2.888)
GAC 3	(-2.912)	-1.8384	-1.2816	- .1687	.8416	1.4985
GBC 1	-1.8384	- .4316	.8416	(1.811)	(2.721)	(3.770)
GBC 2	(-2.186)	-1.1123	- .0828	1.4985	(2.409)	(3.458)
GBC 3	(-2.912)	-1.8384	-1.1123	- .0828	1.4985	(2.548)
GCC 1	-1.2816	- .5244	.6219	1.4985	(2.409)	(3.458)
GCC 2	(-2.912)	-1.8384	- .8416	.3398	(1.250)	(2.300)
GCC 3	(-3.646)	(-2.572)	-1.4985	- .8416	- .2533	1.4985

Table 2. Continued

	Category					
IMAGE	1	2	3	4	5	6
Yjk	-121.13	-63.1400	-5.1800	47.1700	96.3200	152.9800
Yjk/54	-2.2430	-1.1690	-0.0960	0.8730	1.7840	2.8330
d	1.074	1.073	0.777	0.911	1.049	

Yjk/54 are boundaries

then $C = (0.096 + 0.873) / 2 = 0.4845$

$k = k + C$

shift

k	-1.7590	-0.6850	0.3900	1.3600	2.2700	3.3200

These are shifted boundaries

Table 3. Misregistration Magnitude, Boundary Mean Vale, and SQF

Image A (Conventional Chromatic Separation) (Mag.:0.0~0.1mm, SQF:83.2)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-1.40	82.2	0.2mm	0.65	76.1	0.2mm	0.10	77.7
0.3mm	-1.00	81.0	0.3mm	1.70	72.9	0.3mm	1.45	73.7
0.4mm	-0.40	79.2	0.4mm	2.90	69.3	0.4mm	2.90	69.3
		AVE.80.8			AVE.72.8			AVE.73.6

(GCR Separation) (Mag.:0.0~0.1mm, SQF:83.2)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-1.50	82.5	0.2mm	-0.25	78.7	0.2mm	-0.25	78.7
0.3mm	-1.10	81.3	0.3mm	1.20	74.4	0.3mm	0.70	75.9
0.4mm	-0.70	80.1	0.4mm	2.25	71.3	0.4mm	1.55	73.4
		AVE.81.3			AVE.74.8			AVE.76.0

Image B (Conventional Chromatic Separation) (Mag.:0.0~0.1mm, SQF:83.2)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-1.30	82.0	0.2mm	0.40	77.0	0.2mm	-0.20	78.8
0.3mm	-0.90	80.8	0.3mm	1.90	72.7	0.3mm	1.35	74.3
0.4mm	-0.70	80.2	0.4mm	2.80	70.1	0.4mm	2.40	71.3
		AVE.81.0			AVE.73.3			AVE.74.8

Table 3. Continued

Image B (GCR Separation) (Mag.:0.0~0.1mm, SQF:83.2)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-1.60	82.8	0.2mm	0.00	78.2	0.2mm	-0.30	79.1
0.3mm	-1.10	81.4	0.3mm	1.10	75.0	0.3mm	0.30	77.3
0.4mm	-0.85	80.7	0.4mm	2.35	71.4	0.4mm	1.20	74.7
		AVE.81.6			AVE.74.9			AVE.77.0

Image C (Conventional Chromatic Separation) (Mag.:0.0~0.1mm, SQF:81.8)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-0.70	78.0	0.2mm	1.00	75.9	0.2mm	0.25	76.8
0.3mm	-0.40	77.6	0.3mm	2.30	74.3	0.3mm	1.60	75.1
0.4mm	-0.05	77.2	0.4mm	6.60	69.0	0.4mm	3.30	73.1
		AVE.77.6			AVE.73.1			AVE.75.0

Image C (GCR Separation) (Mag.:0.0~0.1mm, SQF:81.8)

Yellow			Magenta			Cyan		
Mag.	B.V.	SQF	Mag.	B.V.	SQF	Mag.	B.V.	SQF
0.2mm	-1.25	78.6	0.2mm	0.40	76.6	0.2mm	-0.30	77.5
0.3mm	-1.00	78.3	0.3mm	1.75	75.0	0.3mm	1.10	75.4
0.4mm	-0.40	77.6	0.4mm	2.85	73.6	0.4mm	2.10	74.5
		AVE.78.2			AVE.75.1			AVE.75.8

Table 4. The SQF Difference Between Proofs and Separation Methods

Con.D: The SQF differences between misregistered and precisely registered proofs in conventional chromatic separation.
GCR.D: The SQF difference between misregistered and precisely registered proofs in GCR separation.
Sep.D: The SQF differences between two color separation methods.

		Image A			Image B			Image C		
Ink	Mag.	Con.D	GCR.D	Sep.D	Con.D	GCR.D	Sep.D	Con.D	GCR.D	Sep.D
	0.2mm	1.0	0.7	0.3	1.2	0.4	0.8	3.8	3.2	0.6
Yellow	0.3mm	2.2	1.9	0.3	2.4	1.8	0.6	4.2	3.5	0.7
	0.4mm	4.0	3.1	0.9	3.0	2.5	0.5	4.6	4.2	0.4
	0.2mm	7.1	4.5	2.6	6.2	5.0	1.2	5.9	5.2	0.7
Magenta	0.3mm	10.3	8.8	1.5	10.5	8.2	2.3	7.5	6.8	0.7
	0.4mm	13.9	11.9	2.0	13.1	11.8	1.3	12.8	8.2	4.6
	0.2mm	5.5	4.5	1.0	4.4	4.1	0.3	5.0	4.3	0.7
Cyan	0.3mm	9.5	7.3	2.2	8.9	5.9	3.0	6.7	6.0	0.7
	0.4mm	13.9	9.8	4.1	11.9	8.5	3.4	8.7	7.3	1.4

CATEGORY SCALING SHEET

1.excellent, 2.very good, 3.good, 4.acceptable,

5.unsatisfactory, 6.poor, 7.unusable

AC (1)	BC (1)	CC (1)
AG______	BG______	CG______

C.:

I	II	III
AI1______	AII1______	AIII1______
AI2______	AII2______	AIII2______
AI3______	AII3______	AIII3______
BI1______	BII1______	BIII1______
BI2______	BII2______	BIII2______
BI3______	BII3______	BIII3______
CI1______	CII1______	CIII1______
CI2______	CII2______	CIII2______
CI3______	CII3______	CIII3______

G.:

AI1______	AII1______	AIII1______
AI2______	AII2______	AIII2______
AI3______	AII3______	AIII3______
BI1______	BII1______	BIII1______
BI2______	BII2______	BIII2______
BI3______	BII3______	BIII3______
CI1______	CII1______	CIII1______
CI2______	CII2______	CIII2______
CI3______	CII3______	CIII3______

Signature:____________, Date:__/__/__, Pro:__, Gen:__

TABLE 5

IMAGE A 83.2 (81.0, 85.4)

		YELLOW			MAGENTA			CYAN	
CHROMATIC		95% C.I.			95% C.I.			95% C.I.	
0.2mm	82.2	80.2	84.2	76.1	74.9	77.2	77.7	76.5	78.9
0.3mm	81	79.3	82.7	72.9	71.6	74.3	73.7	72.4	74.9
0.4mm	79.2	77.8	80.6	69.3	67.3	71.3	69.3	67.3	71.3
GCR									
0.2mm	82.5	80.5	84.5	78.7	77.4	80.1	78.7	77.4	80.1
0.3mm	81.3	79.5	83.1	74.4	73.2	75.6	75.9	74.8	77.1
0.4mm	80.1	78.5	81.7	71.3	69.7	72.9	73.4	72.1	74.7

IMAGE B 83.2 (82.1, 84.3)

		YELLOW			MAGENTA			CYAN	
CHROMATIC		95% C.I.			95% C.I.			95% C.I.	
0.2mm	82	81	83	77	76.5	77.6	78.8	78.1	79.5
0.3mm	80.8	80	81.6	72.7	72	73.5	74.3	73.7	75
0.4mm	80.2	79.5	81	70.1	69.1	71.1	71.3	70.4	72.2
GCR									
0.2mm	82.8	81.8	83.9	78.2	77.6	78.8	79.1	78.4	79.8
0.3mm	81.4	80.5	82.3	75	74.4	75.6	77.3	76.8	77.9
0.4mm	80.7	79.9	81.5	71.4	70.5	72.3	74.7	74.1	75.3

IMAGE C 81.8 (81.0, 82.6)

		YELLOW			MAGENTA			CYAN	
CHROMATIC		95% C.I.			95% C.I.			95% C.I.	
0.2mm	78	77.2	78.8	75.9	75.3	76.5	76.8	76.1	77.5
0.3mm	77.6	76.8	78.4	74.3	73.7	74.9	75.1	74.5	75.7
0.4mm	77.2	76.5	77.9	69	67.6	70.4	73.1	72.4	73.8
GCR									
0.2mm	78.6	77.7	79.5	76.6	75.9	77.3	77.5	76.7	78.3
0.3mm	78.3	77.4	79.2	75	74.4	75.6	75.4	74.8	76
0.4mm	77.6	76.8	78.4	73.6	73	74.2	74.5	73.9	75.1