GATF FREQUENCY MODULATED ACUTANCE GUIDE

by

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Abstract-This paper describes the development and use of the GATF Frequency Modulated Acutance Guide, herein referred to as the "FM Target." The FM Target was devised in an effort to provide the graphic arts industry with a means of measuring an index of acutance, which would correlate with the visual sensation of image sharpness. The design of the FM Target and the derivation of the acutance index are presented. The historical background of the pursuit of measures of sharpness and acutance is examined. The preliminary results of the use of the FM target on film and paper are shown.

INTRODUCTION

The printing industry relies on subjective evaluation of printed samples for certain aspects of quality control. Historically, this has been necessitated by the complex nature of visual perception, and by the wide variety of original subjects and end product requirements. This work examines the psychometric attribute of image sharpness and proposes an evaluative technique and a new test image aimed at providing a quantitative index that correlates with sharpness. The new test image is the GATF Frequency Modulated Acutance Guide or the FM Target (Figure 1). This target consists of a series of distinct patches containing precision line elements distributed in a frequency modulated array. That is, all line elements have the same width (15 microns), but they vary in the frequency with which they occur from a coarse pattern of 300 cycles per inch to a fine pattern of 1,400 cycles per inch.

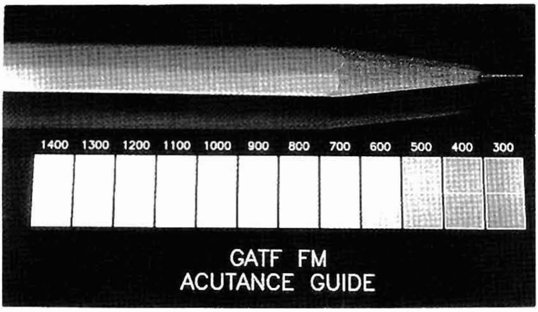


Figure 1 GATF FM Acutance Guide

The distances between line elements varies from 69.66 microns at 300 cycles to 3.14 microns at 1,400 cycles. A chrome-on-glass master image was used to provide the high precision line and space requirements for the target.

The FM target is used to evaluate the sharpness of printed pieces, plates, proofs, or films. The method of analysis requires the use of a reflection or transmission densitometer--a commonly available analysis tool in the graphic arts industry. Optical density readings are made from the printed target and compared to theoretical predicted optical densities for perfectly rendered targets at each spatial frequency. The ratios of the actual and predicted densities are used to calculate an index of acutance (an objectively measurable correlate of sharpness). Preliminary experimental results have shown the need to correct the various anomalies of the printing system to obtain useful data with the FM target.

The historical background of sharpness and acutance measurements are discussed. The theoretical basis for the calculation of the index of acutance is explained, and the preliminary experimental results using the FM target on printed samples and graphic arts films are examined.

BACKGROUND

The sensation of image sharpness is widely acknowledged to be an important visual attribute in evaluating the quality of printed reproductions. However, objective measurement of image sharpness is not attainable because sharpness is a psychometric evaluation based on several factors. These include image register, subject matter, edge enhancement, density range, and resolution.

Efforts to develop a metric that correlates with the subjective sense of sharpness were described by Ross[1] in 1924. He described a technique whereby a microdensitometric tracing of a sharp-edged element was used to construct an edge density profile. Ross postulated that a relationship existed between the characteristics of the edge profile and the apparent sharpness of the image.

In the 1940, Romer and Selwyn[2] used the term "acutance" to distinguish between the subjective impression of sharpness and the objective measurement of the optical density gradient made by a microdensitometric trace across the edge of an image.

In the early 1950 there was renewed interest in the subject by several investigators. Wolfe and Eisen[3] conducted a test of the psychometric evaluation of sharpness. They recognized that sharpness is a subjective concept that cannot be objectively measured, but they felt that a correlation might be formed between an objective index and the sensation of sharpness. Their work utilized a series of photographic prints of the same subject but differing degrees of sharpness. The sharpness was manipulated by using different negative materials. Observers were used to rank the photographic prints according to their sharpness. Good agreement was found between the rankings and the data were manipulated to provide numerical values for the subjectively determined sharpness. Wolfe and Eisen warned that "It is sometimes assumed that resolving power is the significant measure of the performance of a reproducing system with respect to image definition." (p. 919). However, they found that the print with the maximum resolving power did not have the highest sharpness.

Higgins and Jones[4] extended the work of Wolfe and Eisen in their investigation into the relationship between sharpness and resolving power in photographic prints. Using the data of Wolfe and Eisen, they found a correlation between the psychometric evaluation of sharpness and an index of acutance calculated from edge density tracings. Higgins and Jones concluded that the resolving power of the imaging system must satisfy the limit set by the eye for a given viewing condition,. However, resolving power was not found to furnish consistent information about the perceived sharpness of prints.

Higgins and Wolfe[5] examined cases where sharpness and resolving power have an effect on image definition, which they defined as "the quality aspect of the photo that is associated with the clarity of detail." (p. 121). Sharpness was defined as "the impression made on the mind of an observer when examining the boundaries of well resolved elements of detail." (p. 122). The experiment utilized a series of photographic prints on which the graininess and tonal characteristics were held constant by using the same materials and processing for all prints. Sharpness and resolution were varied by changing the distance from the lens to the film. A three-part test subject consisting of a photographic image to the judged for definition, a graduated set of lines for determining resolving power, and a sharp-edge element for measuring acutance. Higgins and Wolfe concluded from the analysis of their data that, "When graininess and tone reproduction are constant and resolving power is adequate to reproduce all the detail that can be observed under the conditions of viewing, acutance, correlates well with definition." (p. 129). However, resolution becomes an important component of definition if it drops below the value required to render all the detail that can be observed.

The issues of resolution and sharpness in lithographic printing were studied by Jorgensen [6,7,8] in the early 1960s. Jorgensen attempted to develop means of evaluating and quantifying print quality attributes that can be distinguished as independent of the subject matter of the image. His efforts utilized the Star Target, a circular series of pie-shaped wedges. Star Targets had long been used for measuring the resolution of camera lenses, and they proved adequate for measuring the resolution of lithographic printing. Beginning from the premise that the observer's impression of sharpness can be predicted from microdensitometric traces across sharp edges in the image, Jorgensen postulated that, "A more complete description of an image could be to determine the ratio of the reflectance changes across various size detail or lines in the original to their corresponding reflectance change in the lithographic print" (1963, p. 2). Jorgensen's approach used a scanning microdensitometer to determine an edge gradient profile from which a spread function was calculated. Fourier transforms of the spread function were used, but the results were confounded by characteristics of the lithographic printing system. The presence of slur, image spread, and doubling had the effect of adding higher harmonics into the sine wave analysis. In this respect, lithographic printing was found to differ significantly from photographic systems in which the same technique had been used successfully by Perrin[9].

In 1987 Tanaka and Abe[10] measured the acutance of type images using video camera input. They defined acutance as the summation of density differences of pixels in the type in relation to the upper and lower thresholds for density. Edge smoothness was calculated in terms of the standard deviation of pixels from the regression line representing a theoretical sharp edge. Several reproduction systems were compared with respect to their acutance and edge smoothness.

Field[11] reviewed the aspects of image structure as related to print quality in lithography. Overall image definition was influenced primarily by resolution and sharpness. He identifies three distinct components of image sharpness: the minor contrast of the printed image, the register accuracy in process color work, and the edge enhancement performed on the image during the color separation process. Field observes that substrates with high brightness and low internal light scatter have greater sharpness. Furthermore, images with higher density range have higher sharpness. Field points out that "density range may be increased by increasing ink film thickness, but this tactic will result in lower resolution." (p. 197).

The register latitude for a given picture varies with the amount of detail and color contrast in the image and with the screen ruling selected for the job. Edge enhancement is a variable and depends on the preferences of the customer, the sharpness of the photographic original, and the requirements of the printing system. Field reports that optimization conditions are not clear in the case of sharpness. In practice, compromises are necessary between optimum sharpness and the needs for tone and color reproduction.

Webb[12] investigated issues related to edge enhancement in color printing. The use of electronic scanners for making color separations provides the means for producing a considerable range and magnitude of electronic edge enhancement effects through unsharp masking (USM). Webb lists three functions that are accomplished by USM. It must correct for the modulation transfer function (MTF) limitations in originals due to the materials and imaging equipment. It must allow for limitations of the reproduction process. It must provide a means for editorial change to alter the visual impact of the image. The performance of unsharp masking in electronic scanners is constrained by considerations of resolution, screen, intensity, fringing, and enlargement. Sharpness appearance is influenced by tonal reproduction and frequency response. Webb proposes research that must precede successful quantification of the perceived sharpness of images. He states the need for the inclusion of edge effects in the brightness model.

Thus, there has been prolonged interest in the measurement and evaluation of image sharpness. The calculation of acutance form microdensitometric traces across a sharp-edged image has been found for some imaging systems to have a useful correlation with perceived sharpness. A standard method for measuring acutance is given in the SPSE Handbook of Photographic Science and Engineering.[13] However, this technique is not available to the printer since it involves specialized equipment. The FM Target is designed to provide the printer with an alternative means for calculating acutance from readily available instrumentation.

TEST IMAGE

The FM Target is a unique test image for the printing industry in that it utilizes line elements of a single width and various spatial frequencies. The FM Target provides a measure of resolution and a means of indicating image sharpness.

There are several test images available to the printing industry that have line elements, which vary in size and frequency. Traditionally, these have been used solely for the measurement of resolution. Some of the commonly available targets are:

RIT Three-Bar Target, a resolution guide developed in the early 1950s in cooperation with the U.S. Air Force.

UPC Printability Gauge, a guide used to determine the bar-width reductions for printing UPC symbols. This target is also used during press runs as a quality control device for the printed UPC symbols.

NBS SRM 1010A, a five bar target available from the National Bureau of Standards used to measure the resolving power of photo systems.

Stouffer Resolution Guide, a test image incorporating tapered lines in both positive and negative orientation used to measure the resolutions of film, plates and ink transfer.

Dupont Spread and Choke Target, a test image containing line and star patterns used to evaluate the extent and sharpness of film images which have been spread or choked.

Kodak Contact Control Guide, a target that features a tapered-line element for control of chokes and spreads. This target also contains geometric patterns useful in the evaluation of sharpness.

UGRA PCW, a plate control wedge including circular microline elements in both positive and negative orientation to measure resolution and control exposure.

Brunner Print Control Strip, a test image that incorporates microlines for the evaluation of plate exposure.

In addition, a number of graphic arts patents have been awarded for test images and methods that are considered to be unique. A representative list of patents for devices with some similarity to the FM Target follow:

No. 3,393,618, July 23, 1968, Elton Baker, Schneider, Inc.
A stencil for use in the preparation of printing plates and subsequent printing from those plates. The target includes geometric designs that are modulated in both size and frequency.

No. 3,998,639, December 21, 1976, Feldman and White, Bell Telephone Laboratories.
A test target containing fine line features for use in the manufacture of electronic circuits. The imaged line elements produce a tint that is a visual intermediate of two reference tones.

No. 4,004,923, January 25, 1977, Roy Hensel, American Hoechst Company.
A method of controlling developer activity in the processing of photosensitive printing plates. A test pattern comprised of geometric designs is exposed on the plate to provide a visual indication of exposure conditions.

No. 4,183,659, January 15, 1980, Felix Brunner, Corippo, Switzerland.
A method to control changes in line thickness during photographic reproduction. A test image is used with fine lines that are varied in both size and frequency.

No. 4,288,157, September 8, 1981, Felix Brunner, Corippo, Switzerland.
A measure of controlling quality in the reproduction of images. A geometric pattern is used to evaluate image quality throughout the reproduction process.

No. 4,419,426, December ,1983, Christof Kehl, Hell, Inc.
A method and test pattern for evaluating the quality of phototypesetting. Geometric patterns are used to determine when a cathode ray tube is over or under-exposing photo sensitive material.

No. 4,527,333, July 9, 1985, Richard Warner, GATF.
A device for indicating quantitative changes in dot area on prints, plate, proofs, or film. A geometric pattern is used to measure the mechanical dot gain of a printing system.

No. 4,566,192, January 28, 1986, Hawkins and Rivoli, Harris Corporation.
A pattern for determining the dimensions of projected or printed figures. A geometric pattern is used to maintain accurate dimensions during the manufacture of semiconductor wafers.

The GATF FM Target is a film image with line elements of 15 microns. This dimension was chosen because virtually all lithographic printing systems can reproduce an element of this size. There are 12 frequencies on the FM Target ranging in 100-cycle intervals from 300 to 1,400 cycles per inch, where a cycle is a line-space pair. The FM Target has two 5-mm square fields of straight lines at each frequency. The orientations of the two line patterns are perpendicular to each other. This was done to show any directional effects influencing the printed target. The dimensions of the entire target are 0.5 x 2.5-in. It is conceived that not all frequencies will be imaged for every application. For example, it has been found that some printing plates are unable to resolve the line patterns finer than 1,100 cycles, and duplication films must be underexposed to hold the 1,400-cycle pattern.

ACUTANCE INDEX

The calculation of an acutance index for the FM Target is accomplished by determining theoretical density values for each frequency and forming a ratio with the actual densities. The ratios are then plotted. Interpretation of the plots yields information related to the sharpness of the printed image.

For the equations which follow the following terms are used consistently.

λ_I = wavelength of the repeating pattern of the sharp-edged lines of constant width k and space X_i

k = width of sharp-edged line elements

X_i = distance between line elements

f_i = spatial frequency of the repeating pattern of lines of constant width k, and space X_i

D_s = measured optical density of a solid area

D_p = optical density of the paper substrate

R_c = theoretical optical reflectance of a given segment of the FM Target

R_p = measured optical reflectance of the paper substrate

R_s = measured optical reflectance of the solid area "s" as show in Figure 1

D_c = theoretical integrated optical density of a given cycle

D_{rc}= measured integrated optical density of a given cycle

R_{rc}= measured optical reflectance of a given cycle

To find the theoretical optical density for the FM target an area of unit square was first defined as shown in Equation 1.

$$ASQi = (k + x_i)^2 = k^2 + 2kx_i + x_i^2$$

Equation 1

Next, the percentage of the area occupied by line element for any given frequency can be calculated (Equation 2).

$$\mathrm{ALfi} = \frac{k^2 + kx_i}{k^2 + 2kx_i + x_i^2}$$

Equation 2

Similarly, the percentage of the area occupied by paper is determined (equation 3).

$$\mathrm{APfi} = \frac{1 - k^2 + kx_i}{k^2 + 2kx_i + x_i^2}$$

Equation 3

By combining equations 2 and 3, the theoretical optical reflectance of any selected segment of the FM Target can be calculated using equation 4.

$$R_c = R_p\left(1 - \frac{k^2 + kx_i}{k^2\ 2kx_i + x_i}\right) + R_s\left(1 - \frac{k^2 + kx_i}{k^2\ 2kx_i + x_i}\right)$$

Equation 4 Theoretical reflectance of selected target element

It follows that the theoretical optical density for any selected segment of the FM target can be computed as shown in equation 5.

$$D_c = \log\left(\frac{1}{R_c}\right) = \log\left[\frac{1}{10^{-D_p}\left(1 - \dfrac{k^2 + k(\frac{1}{f_i} - k)}{k^2 + 2k\left(\frac{1}{f_i} - k\right) + \left(\frac{1}{f_i} - k\right)^2}\right) + 10^{-D_s}\left(\dfrac{k^2 + k\left(\frac{1}{f_i} - k\right)}{k^2 + 2k\left(\frac{1}{f_i} - k\right) + \left(\frac{1}{f_i} - k\right)^2}\right)}\right]$$

Equation 5 Theoretical optical density of target element

The index of acutance is then calculated as the ratio of actual optical density divided by predicted density. If the FM Target is imaged perfectly, then the ratio of actual density to theoretical density will equal 1.0. If the real density is higher than the predicted density (due to ink spread or unsharp line edges) then the ratio will be greater than 1.0.

Since the purpose of the target is to be sensitive to unsharp line edges, it is desirable to introduce a correction factor to account for the portion of the density gain that is due to image spread (dot gain). The first approach to this correction factor was to let fmax equal the maximum frequency of the imaged FM Target where the sharp-edged line elements are first resolved. Let kt equal the width of the sharp-edged line elements in the original light-transmitting FM Target. Let ▲f equal the absolute value of the difference in frequency between adjustment segments in the FM Target. The correction for exposure of the imaged line width, k, of the sharp-edged line elements is given by equation 6.

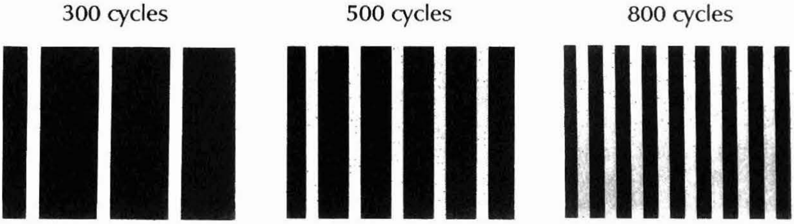
$$k = k_t + \left| \frac{1}{f_{max} + |\Delta f|} - k_t \right|$$

Equation 6 Correction factor

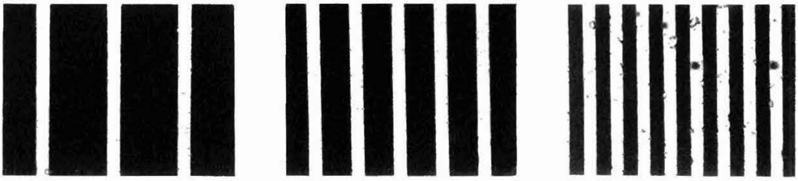
The correction factor calculated from Equation 6 performed well with initial tests on film. However, when printed samples were tested, it was found to be more convenient to measure the target elements with a reflection densitometer and identify the first element that was equal to the solid density of the press sheet. The corrected line width is determined from the frequency of that element by assuming that the lines have grown to a position of touching and that the line width equals the width of the space plus the width of the original line.

EXPERIMENTAL FINDINGS

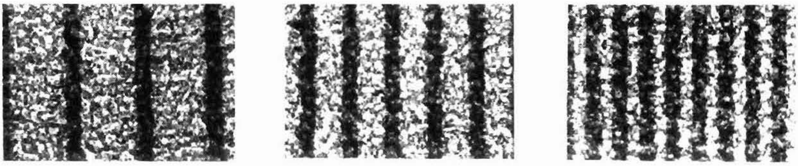
Initial experiments have been conducted using the FM Target on film, plates, and printed sheets. Figure 2 shows photomicrographs of three selected target frequencies (300, 500, and 800 Figure 2 Photomicrographs of Master, Duplicate, and Plate cycles) on the original glass master, duplicating film, and a printing plate. The entire series of photomicrographs were used to quantify dimensional changes that occurred during these processing steps and to measure the accuracy of the glass master. The dimensions on the glass master were found to be extremely accurate and the dimensional changes occurring during film duplication and platemaking were consistent across all frequencies.



glass master



duplicating film



printing plate

Figure 2

The initial experiments were carried out on a variety of graphic arts duplicating and contacting films. During the film experiments the acutance index was calculated as the ratio of predicted densities divided by real densities (the inverse of the current acutance index). Thus, an ideal reproduction would have an index of 1.0, and a less sharp reproduction results in values lower than one. It is assumed that values higher than one resulted from error in the determination of the corrected line width.

Figure 3 shows the plot of a typical duplicating film. An interpretation of this plot is that the duplicating film has high acutance and that it maintains consistent sharpness up to the 900-cycle element after which the acutance declines. The straight-line characteristic of the coarser frequencies indicated success in the progression of prediction.

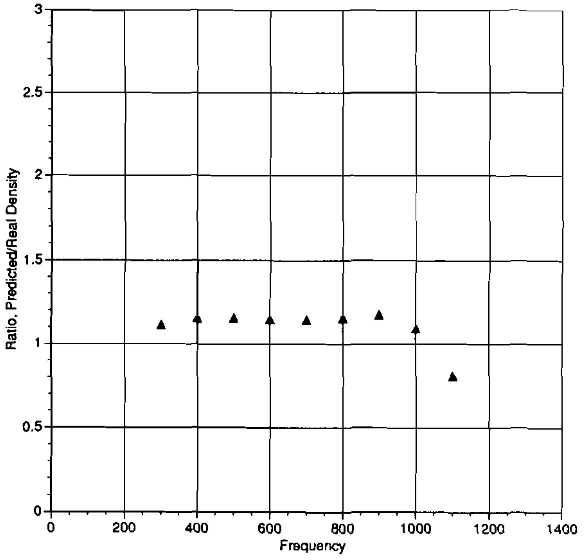


Figure 3 FM Target Imaged on Duplicating Film

Figure 4 shows a similar plot comparing graphic arts contact film with high-contrast reflective material. These plots show a considerably higher acutance index for the film than that found on the paper. An anomaly is seen in the finer frequency elements. Although the contact film decreases in acutance in a manner similar to the duplication film, the acutance index of the reflective material actually increases. One possible explanation for this effect is that the maximum frequency chosen for calculating the correction factor was in error.

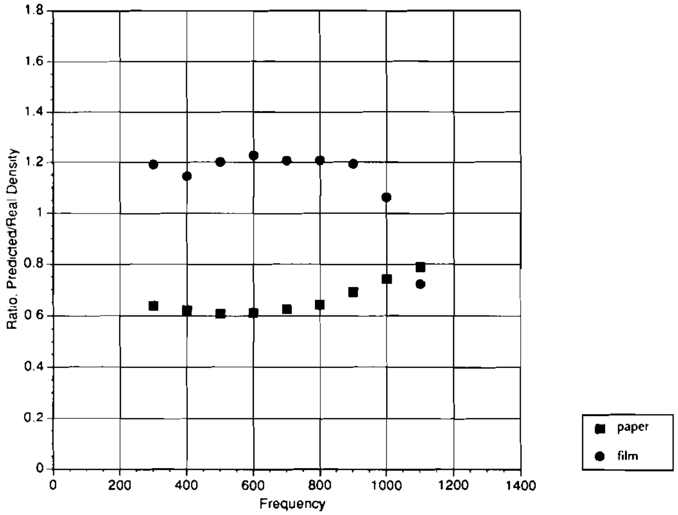


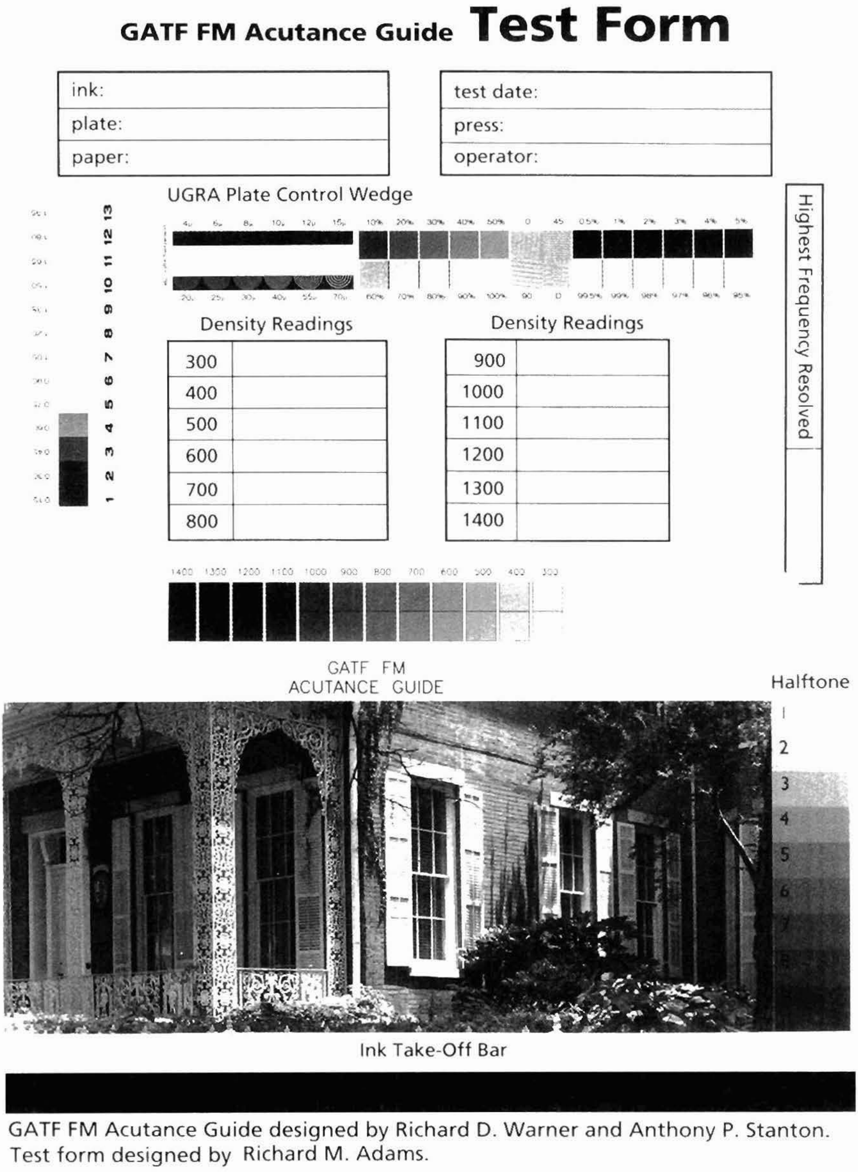
Figure 4

The targets was next tested on the printing press using both coated and uncoated paper. To perform this test, a small one-color test form was devised (figure 5) so that other QC targets and a pictorial image could be evaluated along with the FM Target.

The results of the press test were visually evaluated as well as measured with a densitometer. The image on coated paper was noticeably sharper than the image on uncoated paper.

The results of the densitometric analysis of the FM Target are shown in Figure 6. In this case, the acutance ratios were computed as the actual densities divided by the predicted densities. Therefore, higher values indicate lower acutances.

Examination of Figure 6 offers some promise and leaves some unanswered questions. In the coarser frequencies, this acutance index for coated paper is lower than for uncoated paper. This is consistent with the visual evaluation. However, the lines cross in the middle frequencies (500 cycles), and the coated paper shows a higher acutance index through the finer frequencies. Furthermore, the plots show no flat section in the coarser frequencies as was exhibited on the experiments with film. The investigation of these anomalies is ongoing.



GATF FM Acutance Guide Test Form

ink:
plate:
paper:

test date:
press:
operator:

UGRA Plate Control Wedge

Density Readings

300	
400	
500	
600	
700	
800	

Density Readings

900	
1000	
1100	
1200	
1300	
1400	

Highest Frequency Resolved

Ink Take-Off Bar

GATF FM Acutance Guide designed by Richard D. Warner and Anthony P. Stanton.
Test form designed by Richard M. Adams.

Figure 5 GATF FM Acutance Guide Test Form

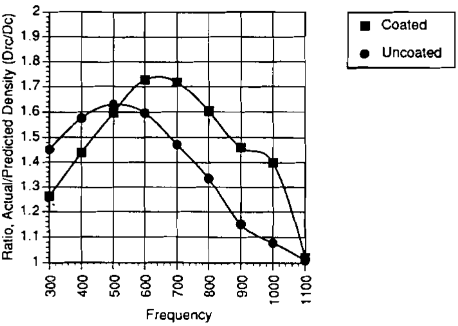


Figure 6

SUMMARY

This paper has presented a new measuring device, the GATF FM Acutance Guide and a method of analysis using a densitometer. The historical background and theoretical basis for an acutance index have been presented. The goal is to provide an objective index that correlates with the visual sensation of sharpness. The proposed acutance index differs from the accepted measures of acutance in that a commonly available reflection or transmission densitometer can be used. Thus, the measurement of the acutance index could take place in the printing plant. The calculations could be performed by a computer based on density readings. The initial results have been more promising on film than on printed substrates. However, work is continuing to improve the method for ink-on-paper samples.

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