MEASUREMENT OF MTF OF GRAPHIC ARTS PRODUCTS

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Abstract:

Modulation transfer function (MTF) and spread function are performance evaluation tools widely used in optical and photographic imaging. Use of these tools has been sparse in the graphic arts industry. Part of the reason for this is attributable to the difficulty in determining the MTF of graphic arts products. A technical approach is presented that provides an estimate of the spread function of these high contrast materials. This methodology is compatible with instrumentation readily available in the typical graphic arts film laboratory. The use of this data to provide insight to graphic arts applications is also discussed.

Introduction

When light enters the emulsion of a photographic film it is scattered by the optical characteristics of the emulsion. This scattering has a direct effect on the relationship between the image that reaches the film (sometimes called the aerial image) and the latent image recorded in the film. Classically there are two ways in which this mechanism is interpreted and understood. One is called the modulation transfer function (MTF), also called the contrast transfer function (CTF) by some authors. The other is the spread function (SF), which is related to the MTF by a Fourier transform. The MTF indicates the decrease in amplitude or modulation of a sine-wave signal, caused by spread as a function of the spatial frequency. The SF indicates the distribution of the effective intensity in the vicinity of an exposed very small slit. These two

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functions are related to each other by a Fourier transform.

Frieser (1960) proposed a model for the MTF and spread function of photographic film that has been used successfully in work with films of moderate contrast such as microfilm and aerial film. His equations are as follows:

MTF

$$m(\nu) = 1/(1 + (\pi k \nu / 2.3)^2) \tag{1}$$

SF

$$I(x) = (2.3/k) * 10^{(-2\,|x|/k)} \tag{2}$$

where:
- m = modulation
- I = intensity
- ν = spatial frequency in cycles/mm
- x = distance in microns
- k = Frieser coefficient

Figure 1 and Figure 2 show plots of these functions for a value of k equal to 8.

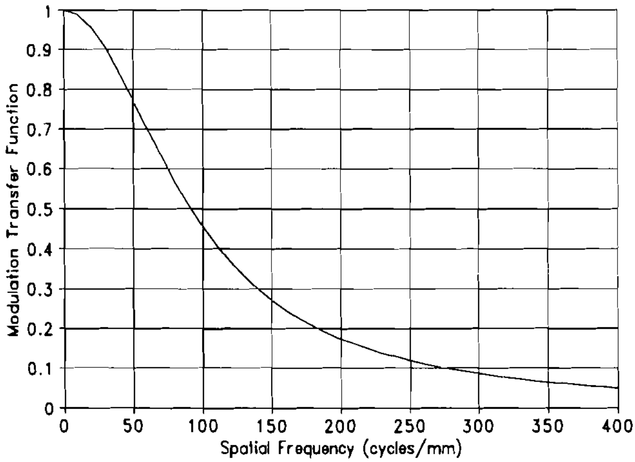

Figure 1. Plot of Equation 1 for k = 8

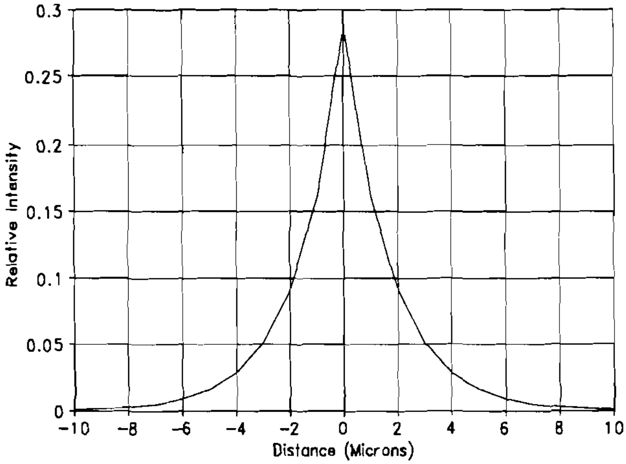

Figure 2. Plot of Equation 2 for k = 8.

Application to Graphic Arts

A model that is easy to understand from a graphic arts perspective is to consider the light distribution at the edge of a line. If we were to take collimated light and use a razor blade with an infinitely sharp edge to create a line between exposure and no exposure on a piece of film, the light reaching the film would have an intensity profile as shown in Figure 3.

However, the distribution of light inside the film emulsion that created the latent image would not show this same abrupt transition but would look more like Figure 4. This intensity profile can be computed by convoluting the intensity profile of Figure 3 with the point-spread function shown in Figure 2 and described by Equation 2.

This relationship is given by:

$$I(x) = (1/2) * 10^{(x/k)} \quad \text{for } x = -\text{infinity to } 0 \quad (3)$$

$$I(x) = 1 - (1/2) * 10^{(-x/k)} \quad \text{for } x = 0 \text{ to infinity} \quad (4)$$

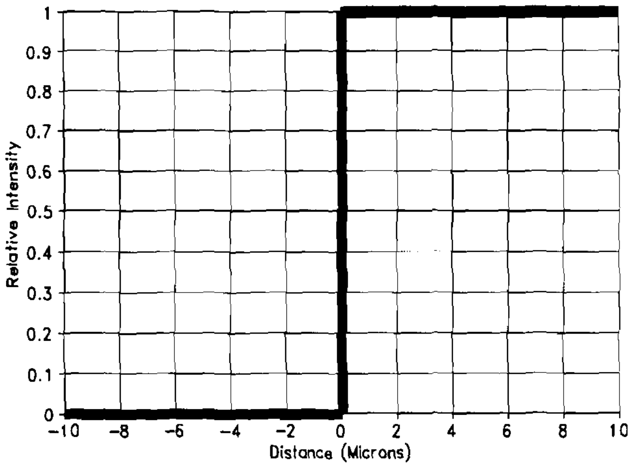

Figure 3. Ideal Intensity Profile

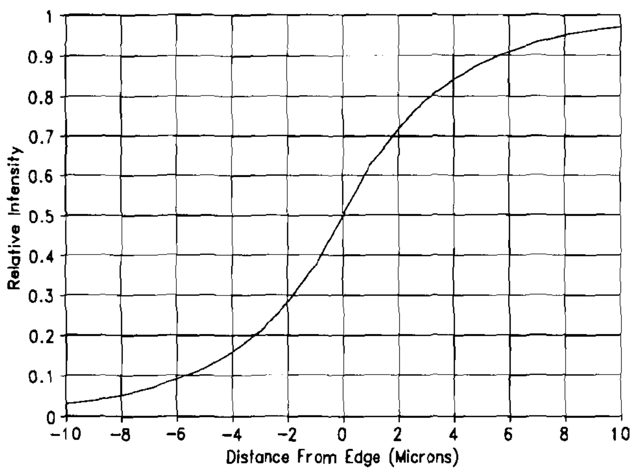

Figure 4. Effective Intensity Profile.

From the graphic arts point of view, this is the intensity distribution at the edge of a halftone dot or a line, exposed from a perfect hard dot master, using a point light source. This is easier to visualize if we replot Figure 4 in log intensity space and also add a second edge to represent the cross section of a dot or a line. Figure 5 shows the effective intensity profile that one would get in a typical graphic arts film where the width of the line is 30 microns (30 microns is also the diameter of a 10 % circular dot of a 150 line per inch halftone screen).

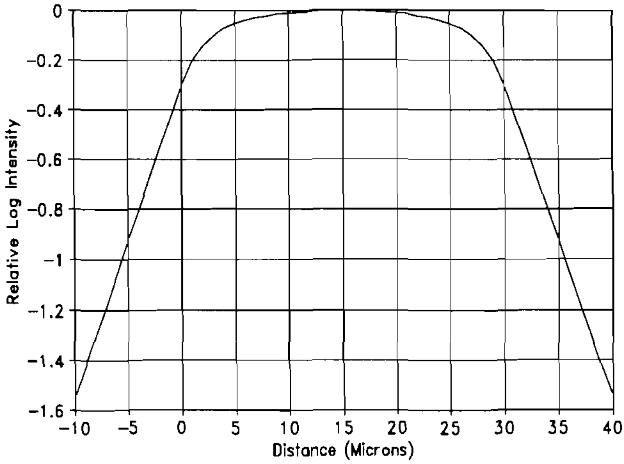

Figure 5. Log Intensity vs Distance.

If we assume that the ideal graphic arts film has a D Log E curve that approaches a step function, we can see that it will clip or threshold the intensity profile at the point that corresponds to the critical exposure. Thus the line width or dot radius will vary with changes in exposure as a function of the slope of the intensity profile. The practical implications are immediately obvious. Our experience tells us that lines and dots change size with exposure, and a way to characterize the rate of this change is extremely useful.

The real problem however is to measure MTF or point-spread function. All of the classic measurement techniques are based on the use of microdensitometer traces of sinusoidal targets or edge profiles, which are then manipulated through the D Log E curve to deduce the relationship between the aerial image and the latent image. Unfortunately the high contrast, high density, and high resolution of the typical graphic arts film introduces so much noise and uncertainty that these techniques have not proven useful for such products.

An Experimental Estimation Technique

Given that absolute measures of the point spread function are not easily determined we assumed that relative measures were still of significant value for the analysis of graphic arts materials. The search for estimation techniques led us back to the physical evidence of the mechanism as seen in graphic arts. When measured carefully, dots change size with exposure in all graphic arts products. Further, the larger the perimeter to area relationship, the greater the degree of change. A simple measure of the potential sensitivity of this measurement is that the difference in radius between a 49% circular dot of a 150 line/inch screen and a 50% dot is 0.68 microns.

The hypothesis was that the relationship between edge movement and intensity could be predicted based on the change in dot size of a graphic arts screen tint of circular dots. This was based on the following assumptions:

1. The D log E curve is high enough in contrast so that there will be consistent clipping of the intensity profile and the change in tint density (and computed dot area and radius) will be a function only of the intensity profile of the spread function.
2. The movement of the edge is small compared to the diameter of the dot so that the curvature of the edge does not need to be considered.
3. The Frieser model is adequate to model the behavior of graphic arts films over the range of interest and k can be derived from edge gradient data.

Experimental data was collected using 150 line per inch circular dot screen tints of 30% and 70% dot area. These values were chosen to allow the possible effects of a concave vs a convex perimeter to be monitored and to be as near the 50% dot as possible without danger of dots touching after spreading. (The 70% tint is the inverse of the 30% tint. That is, the 70% tint can be thought of as a 30 % circular hole in an opaque surround rather than a 30% opaque circular area on a clear surround.) These were exposed emulsion-to-emulsion in a contact frame, onto the film of interest. An exposure series was created by overlaying the tints with a carbon step tablet of measured density. The density of the D-min, D-max, and tint area were measured and used to compute dot radius. Dot radius change vs exposure was then plotted and the k value derived.

Figure 6 shows actual data from an early test of a typical graphic arts contact film. The data fit to the Frieser model was excellent. The reference line shown is for the Frieser model (equations 3 and 4 above) with a k of 6.4. Figure 7 shows a similar plot for a reversal film where the reference line is for a k of 10.2. Figure 7 also shows an additional feature that at first was though to be a flaw in the procedure. You will notice that one of the data lines is increasing in slope as exposure increases. In every case this was observed it was related to the data that is derived from the area that was 30% in the original test target.

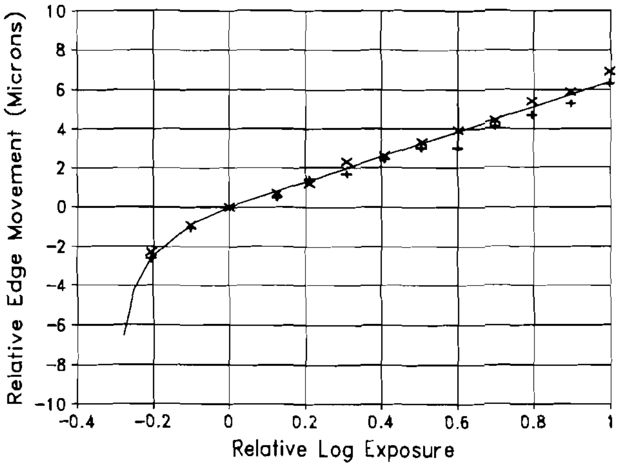

Figure 6. Typical Test Data - Film 1.

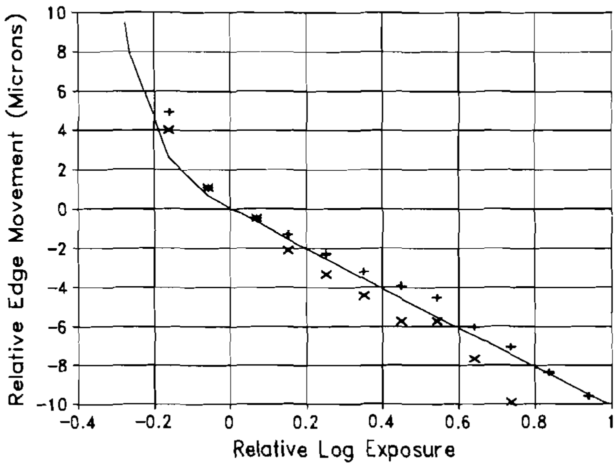

Figure 7. Typical Test Data - Film 2.

Subsequent test with films of varying degrees of halation protection and input dot areas confirmed that the rate of departure from the straight line of the Frieser model is directly related to the degree of halation present in the film being tested and the amount of light present (size of the dot in the input test film).

Figures 8 and 9 show another result that at first was unexpected and thought to be a problem. Figure 8 shows data for a film tested in a rapid access process where nucleation effects were not present. The same film tested in a developer that produced nucleation effects, in that film, provided the data shown in Figure 9. Once it was understood that matching the curve shape was important, and that it was permissible to offset the apparent dot-for-dot exposure point, the presence of chemical spread was apparent and predictable.

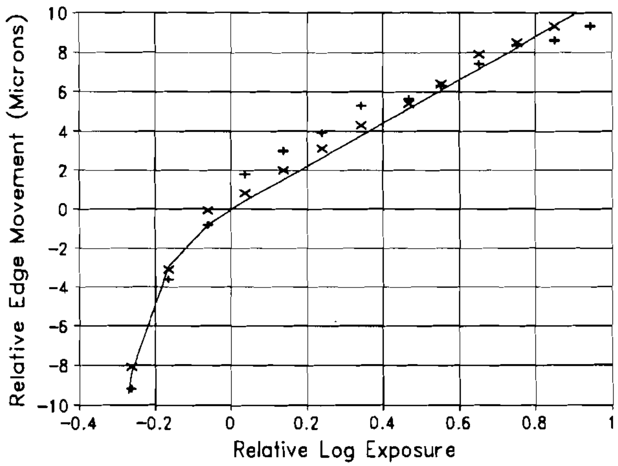

Figure 8. Typical Test Data - Film 3 - Without Nucleation.

Experimental Results

Testing of a wide variety of graphic arts films indicated that the Frieser k valued derived from this test method, when translated into practical working models of halftone film performance, provided consistant and predictable results. The ranking of films in various categories and the predictions of expected results based on these data

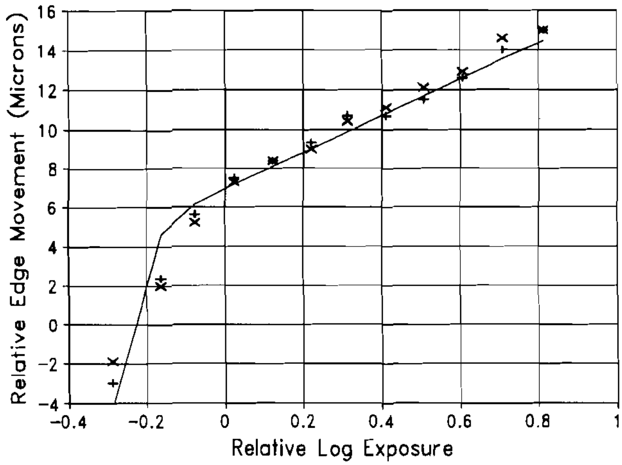

Figure 9. Typical Test Data - Film 3 - With Nucleation.

were as accurate or more accurate than extensive practical testing. The observed nonlinearities associated with the onset of halation effects were also confirmed in practical tests. Both negative working and duplicating films responded as predicted by the test results and model.

The graphic arts films tested all fell within a k value range of 5 to 12. Figure 10 shows the edge movement vs log exposure plot for this minimum and maximum value of k. Figure 11 shows the MTF curves predicted by equation 1 for these same values of k.

Conclusion

The Frieser model for Spread Function works well for graphic arts films over the range tested. It can be used in conjunction with a simple test procedure to derive the MTF and spread function of typical graphic arts products. That test procedure also provides a measure of the amount of chemical spread present and the exposure level at which halation effects may be expected to cause problems.

Typical graphic arts products fall within a performance range defined by a Frieser k value of 5 to 12. This converts to a resolution of 175 to 450 cycles per millimeter at modulation of 10%. Alternatively a 50 % circular dot of a 150 line per inch screen tint can be expected to change in size at a rate of .77 to 1.93 percent dot per 0.1 log exposure change.

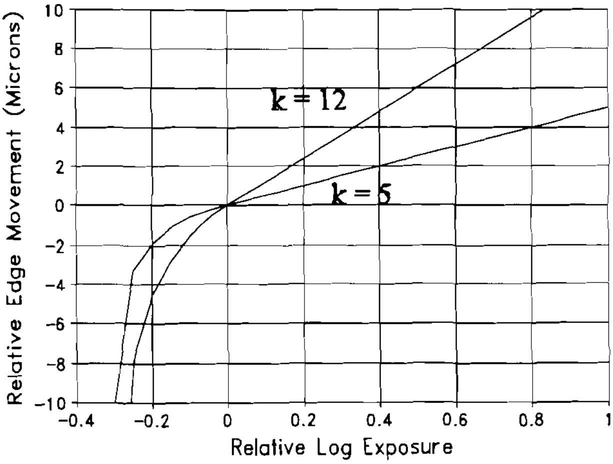

Figure 10. Range of Dot Edge Movement

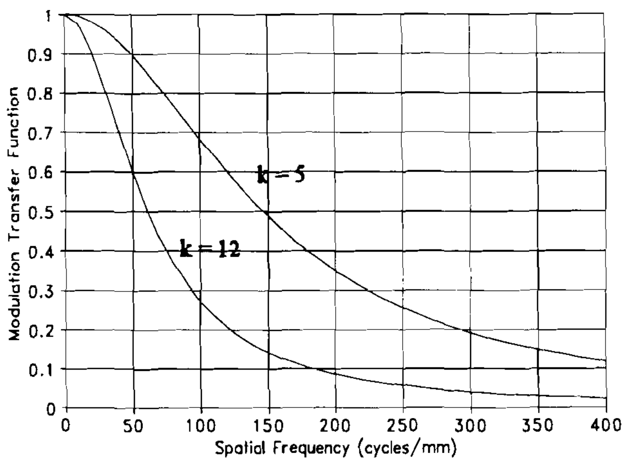

Figure 11. Range of MTF.

The MTF and spread function of graphic arts products can be used in a number of exposure models to predict performance of either the film as an individual element or in combination with optical elements and exposure sources. This type of modeling has not been widely used in the graphic arts in part due to a lack of readily available data for graphic arts products. The procedure described can provide acceptably accurate values for such modeling work.

Literature Cited

Frieser, H.
1960. "Spread Function and Contrast Transfer Function of Photographic Layers", Photogr. Sci. Eng., 4, pp. 324-329