6-1-1973

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THE OBJECTIVE EVALUATION OF IMAGE QUALITY PRODUCED WITH PHYSICAL DEVELOPMENT

by

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A thesis submitted in partial fulfillment of the requirements for a Bachelor of Science Degree in Photographic Science from the Rochester Institute of Technology

June, 1973

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ABSTRACT

This experiment was an analysis of the difference in objective measures of image quality between chemical and physical development methods, including prefixation and postfixation processes. Of particular interest was the process outlined by Matejec[1] for postfixation physical development. An investigation of resolving power and MTF for two fine grain films was carried out for four different development processes all possessing approximately the same speed capability. Both the effect of combined chemical and optical spread functions and the chemical spread alone were investigated through edge analysis using Fourier methods.

A significant increase in image quality was found with the finest grain film (Eastman 5302) for prefixation while a significant decrease was found with the highly active Matejec's physical developer on the same film.

A dye inhibition reaction on the dye sensitized emulsion, Panatomic-x, prevented analysis of image quality for postfixation processes for that film.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of Dr. Snyder of the Mechanical Engineering Department at RIT in helping us with the x-ray imaging involved in this thesis. We also wish to acknowledge the assistance of Roger Jerry and John Nelson, fellow photo-science seniors at RIT, for their help with Matejec's development process.

We are very grateful for the assistance of both of our thesis advisors, M. F. Abouelata and T. H. James, during the course of this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THEORETICAL BACKGROUND

Photographic image structure has been found to be greatly different on physically developed film than for chemically developed film.[2] The chemical development process produces much higher film speed because the covering power of the filimentary silver, produced by reduction of silver halide crystals in the emulsion, is much higher than that of the spherical silver particles produced by physical development. Recently a physical development process was reported by Matejec[3] of AGFA which claims to achieve the same speed as chemical development. Matejec only reported the attainment of comparable speed on a fine grain, cubic, monodisperse AgBr emulsion and reported nothing on the image quality of the process.

With post-fixation physical development it is common for the film to be fixed in an alkaline fixer to prevent destruction of latent image sites; for every site you lose will decrease the speed of the process. To achieve sufficient densities after some of the latent image is destroyed, it becomes necessary to develop the latent image sites until the spherical silver mass is quite large, perhaps even larger than the original grain size in the unfixed film. If this occurrs it will result in a decrease in

image quality measurements such as resolving power and modulation transfer function, from that obtained in chemical processing where the silver for the image comes from the silver halide grain being developed. With chemical development the image particle size is limited by the size of the grains in the emulsion whereas with physical development the image particle size can increase indefinitely as long as the solutions are fresh. When the image particle size becomes larger than that of chemically developed film a decrease in image quality will result. If a sufficient number of latent image sites are available then, with physical development, normal densities can be attained without a loss of image quality or even with an increase in image quality.

In pre-fixation physical development it is not difficult to increase image quality because there are as many developable latent image sites as with chemical development. But with post-fixation physical development a large number of latent image sites are destroyed by the fixer or by oxidation in the wash step between fixation and development, or in the early stages of development. To prevent some latent image destruction in the fixation process the fixer is usually in basic solution, but there still remains some degree of oxidation of the latent image. By performing all of the processing steps, prior to and including development, in a nitrogen atmosphere and with nitrogenated solutions a larger amount of latent image sites are preserved. In Matejec's

work a sulfite wash was used after fixation to remove the fixer and prevent oxidation of the latent image. With this process on an undyed, cubic, monodisperse emulsion, post-fixation physical development attained the same speed as normal chemical development.

Objective measurements of image quality are resolving power and modulation transfer. Measuring resolving power is quite common and has been used for many years to measure image quality. It involves only the imaging of a target, usually of alternating, high contrast black and white bars, onto a film and then reading the target image to find the limiting case of the number of lines per millimeter that can be resolved on the image. Modulation transfer on the other hand can be used to determine the film's response to any signal frequency, in cycles per millimeter, by giving the film modulation at each frequency. This is a much better measurement than resolving power because it gives much more information about the film. Measurement of MTF however requires a great deal of additional work to obtain. MTF is often found by imaging a sinusoidally modulated light source on the film many times and each time at a different frequency. The images are then read on a microdensitometer and the image modulation for each frequency is determined from the image trace. The object modulation, or the modulation of the sinusoidal light source, is also determined. The modulation transfer at a particular frequency is the image modulation

divided by the object modulation. This procedure is performed for many different frequencies and when the results are graphed it gives the curve of the form of the modulation transfer function.

Another more recent method for finding MTF relies on the principles of the Fourier Series and Fourier Transformations.[4] With Fourier Series it becomes possible to break any object distribution into an infinite series consisting of sines and cosines of different frequencies. The exposure distribution of the image of a knife edge on the film can be broken into sines and cosines, and with proper analysis of a microdensitometer edge trace the MTF function can be determined from one exposure.[5] This requires only a good knife edge instead of a series of sinusoidal targets.

The knife edge is imaged on the film to be analysed in the linear portion of the D-LogH curve.[6] The film is then developed according to the desired process and the resulting image is traced on a microdensitometer using a narrow slit, parallel with the knife edge. This edge trace is of the form Density versus Distance. The curve is then converted to Exposure versus Distance by reflection through the D-LogH curve and subsiquent antilogging. This curve is then differentiated to give the curve of the Spread Function for the film-developer combination. The Fourier Transform of the Spread Function, once normalized, gives the Modulation Transfer Function of the film-developer combination.

In this practical application of the Fourier Transform, the Fourier Integral cannot be calculated directly because the equation of the Spread function is not known. Therefore the exact value is closely approximately by a summation process performed after partitioning the Spread Function curve into many small intervals. The Fourier Integral to be evaluated is:

$$F(\omega) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i \omega x} \, dx$$

$$= \int_{-\infty}^{\infty} f(x) \cos 2\pi \omega x \, dx - i \int_{-\infty}^{\infty} f(x) \sin 2\pi \omega x \, dx$$

where f(x) = the Spread Function.

These relationships can be put into the form below by using the symmetry properties of the sine and cosine functions.

$$F(\omega) = \int_{0}^{N_{MAX}} \left[f(x) + f(-x) \right] \cos 2\pi N x \, dx$$

$$- i \int_{0}^{N_{MAX}} \left[f(x) - f(-x) \right] \sin 2\pi N x \, dx$$

This form can then be computed numerically on a high speed computer.[7] With the use of the computer the work involved in the process of finding the system MTF from a knife edge image is greatly reduced.

There are two major factors contributing to image degradation. There is the optical spread produced by scattering of light in the emulsion and the chemical spread of

the image produced by processing.

These two types of image spread can be separated and analysed separately if one of them can be eliminated. This can be done if the optical spread is to be eliminated by exposing with high energy radiation which is not deflected by the grains in the emulsion. In practical applications this is done with low energy x-rays in the neighborhood of 25 KEV peak radiation. When a knife edge which will stop the x-ray is used to image the film, it becomes possible to find the MTF caused by the chemical process separately.

An x-ray knife edge can be constructed with a piece of Platinum-Irridium foil which has had an optical edge machined on one side. This machining is finished by hand lapping the edge with 3 micron size polishing compound.[8] The edge must be approximately 50-75 microns thick to stop low energy x-rays. The imaging is accomplished by exposure with a parallel beam of x-rays onto the edge which is in contact with the film.

These measures of image quality can be used to predict image quality in fine details.[9] This prediction process would be simple for a linear system, but most photographic systems are not linear.[10] The production of density in the film is a function of the covering power of the silver grains produced by development. This is not a linear function of density versus amount of silver produced per unit area. Adjacency effects, which are the major producer of

chemical spread, are a function of mass of silver produced per unit area. They are the result of development products being present in the vicinity of a developing silver mass which act to retard further developer activity in the vicinity. They are not a function of exposure but of the amount of silver being developed. Therefore the adjacency effects are also a nonlinear function of exposure. Different types of measurement systems for MTF will produce different MTF curves. Therefore any mathematical model for prediction of densities in film must, to be accurate, take into account the nonlinearities as well as the particular MTF for the process involved.

Prediction of densities in film begins with the convolution of the exposure distribution on the film with the optical spread function of the film.[11] This is converted to the nominal, or large area density, with the large area D-LogH curve. This is then corrected for the adjacency effects of development according to the relationship below.

$$D_c(x) = \left[D^n(x) + BD^{2n}(x) - D^n(x) \int_{-\infty}^{\infty} b(\eta) D^n(x-\eta)\, d \right]^{1/n}$$

where $D_c(x)$ is the corrected density at point x. $D^n(x)$ is the nominal density at x; B is the area of the chemical spread function; n is the degree of nonlinearity of the relationship between density and mass of silver; $b(\eta)$ is the chemical spread function and $D(x-\eta)$ represents the adjacent

nominal densities. Thus if the optical spread, the chemical spread, the D-LogH relationship and the density to mass of silver relationship are known it becomes possible to predict the density produced by any image distribution. Actual calculations are performed on a high speed computer and produce only small errors.

PROCEDURE

Processing

This experiment uses four different film development processes in the production of images on both Panatomic-x and Eastman 5302 films. The first of these is regular chemical development using straight D-76 processed at 75°F for 5 minutes with both films, then fixed, washed and dried normally according to film data sheets.

The para-phenylenediamine (PPD) physical developer and Matejec's physical developer were mixed up according to the following Table 1 and Table 2.

54.5 ml Part A was added to 300 ml Part B to make a working solution of the PPD physical developer. All steps of the processing were carried out in a 500 ml graduated cylinder with continuous nitrogen stream agitation emitting from a fritted disk in the bottom of the cylinder. The film samples were clipped onto both sides of a long T-shaped strip of plexiglas which was then immersed into the developer for the required time.

After the PPD prefixation development the films were fixed with normal F-6 fixer for 5 min., washed for 20 min. and dried.

Table 1

Para-phenylenediamine Developer Formulation

Part A		Part B	
PPD-2HCL	10.0 g	Na_2SO_3	288.0 g
Na_2SO_3	20.o g	$AgNO_3$	12.0 g
water to	320 ml	.1M Borax	160 ml
		water to	1440 ml

Table 2

Matejec's Developer Formulation

Part One (to be prepared before use)
50g silver nitrate in 100 cc water with 10 cc nitric acid.
The solution is boiled and cooled to remove silver.
Plus 500g Sulfite and 50g bisulfite in 2 liters water.

Part Two (to be mixed with Part One immediately before use)
100g Metol in 2.5L water
75g Sodium bisulfate and 12.5g anhydrous sodium sulfite

The postfixation physical development processes used an alkaline fixer to reduce the risk of oxidizing latent image centers. This fixer consisted of 10g Na_2SO_3, 100g sodium thiosulfate and water to make one liter of solution. Then a series of five 1 % sulfite washes for one minute each were used to remove any thiosulfate residues. Then the film was developed, washed 20 min. and dried.

Matejec's postfixation development process was done in similar continuos nitrogen bubble agitation apparattus using similar fixing and washing but with a different developing agent.

Sensitometric work with PPD postfixation process produced negligible images on Panatomic-x film with 120 min. development time. Matejec's postfixation process gave similar results on Panatomic-x film. This might be caused by some sort of sensitizing dye inhibition of the development process. Since the nature of this thesis is not a study of complex chemical relations but rather image quality, it was decided to discontinue further work with Panatomic-x in the post-fixation processes.[12]

Sensitometry

A set of sensitometric curves for both Panatomic-x and Eastman 5302 were generated in the following manner. An Omega D-2 enlarger was used as a light source with a 55 mm lens 24 inches from the baseboard and the condenser in the

proper position for that lens. An exposure series was made contact printing a Kodak 21 Step Wedge with the best exposures being f/5.6 for 16 sec. on Panatomic-x and f/5.6 for 3 min. on Eastman 5302. Both were developed at 75°F for 5 min. with RIT tray rocking agitation. The DLogE values were plotted and a gamma of 1.0 was calculated for Panatomic-x and a gamma of 1.3 for 5302.

The optimum time for PPD prefixation development was determined to be 90 min. at 75°F. This gave a gamma of 1.4 and no difference in speed for Panatomic-x compared to chemical development. 5302 had a gamma of 1.1 and half stop loss in speed compared to chemical development.

The optimum time for PPD postfixation development was determined to be 120 min. at 75°F. 5302 had a gamma of 1.1 and a $2\frac{1}{2}$ stop loss in speed from chemical development.

Matejec's postfixation process developed for 30 min. at 68°F gave a gamma of 1.4 and a $3\frac{1}{2}$ stop loss in speed for 5302.

All images were thereafter processed with these same conditions.

Resolving Power

The resolving power images were produced by exposing on the RIT microcamera using a high contrast ASA Resolving Power Chart and processing with each film-developer combination. The microcamera gave a reduction of 81x. Exposure

times were 1/50 sec. for Panatomic-x and 1 sec. for 5302 chemically and prefixation physical developed (with a 1.9ND filter before the target). Exposures for postfixation processing were increased to 5 sec. on 5302 film.

Optical and X-ray Knife Edge Images

To obtain information on the effects of optical and chemical spread functions for the films, two different knife edge exposures are needed. These are a normal optical knife edge and a special x-ray exposed edge (which has practically no optical spread function at all).

Optical knife edge images were produced by contact printing a low contrast (silvered on glass) knife edge onto both films. The Omega enlarger was used as a light source with the same conditions previously mentioned for sensitometric work. The exposures used were f/5.6 for 4 sec. on Panatomic-x and f/5.6 for 90 sec. on 5302 for all film-developer processes.

The x-ray edge images were produced by exposing the film in contact with a 50 um Platinum-Irridium foil edge to x-rays of 25 KVolt peak and 15 milliamp settings. The beam coming from the x-ray tube passed through a collimator device which allowed a maximum of 3° beam divergence. The film holder and foil edge were then 6 inches away from the center of the x-ray tube. The exposure times were 3 min. for Panatomic-x

and 8 min. for 5302 for all film-developer combinations.

Modulation Transfer Function

The method used to determine MTF was as follows. All the sensitometric strips for each film-developer combination were traced on the microdensitometer with an effective slit aperture of 2um x 120um and a 30v lamp setting and 10 mm scan speed. From these traces and the actual exposure falling on the step wedge used to make the sensitometric strips, D-LogH curves were plotted for each strip. The actual exposure on the step wedge was calculated to be 1.27 log H (mcs) for Panatomic-x and 2.32 log H (mcs) for 5302.

Next, all the optical and x-ray edge images were traced on the microdensitometer with the same aperture and lamp voltage settings, but with .025 mm scan speed setting. The edge traces (Density versus Distance) were then reflected through the corresponding D-LogH curve for each film-developer combination. This reflection gave Log H values which were plotted against Distance across the image. By antilogging Log H values, Exposure versus Distance curves were plotted. These curves were then differentiated by plotting the slopes of the top half of the curves versus Distance. This is one half of the Spread Function. Since the Spread Function is symmetric it is only necessary to differentiate the left half of the Exposure versus Distance curve.

To get MTF curves the Spread Functions were Fourier Transformed by computer using numerical analysis techniques. Typically, at least one hundred points on the Spread Function need to be Fourier Transformed to get a good approximation of the MTF values by computer. See Figure 1 for an example of the MTF graphical analysis.

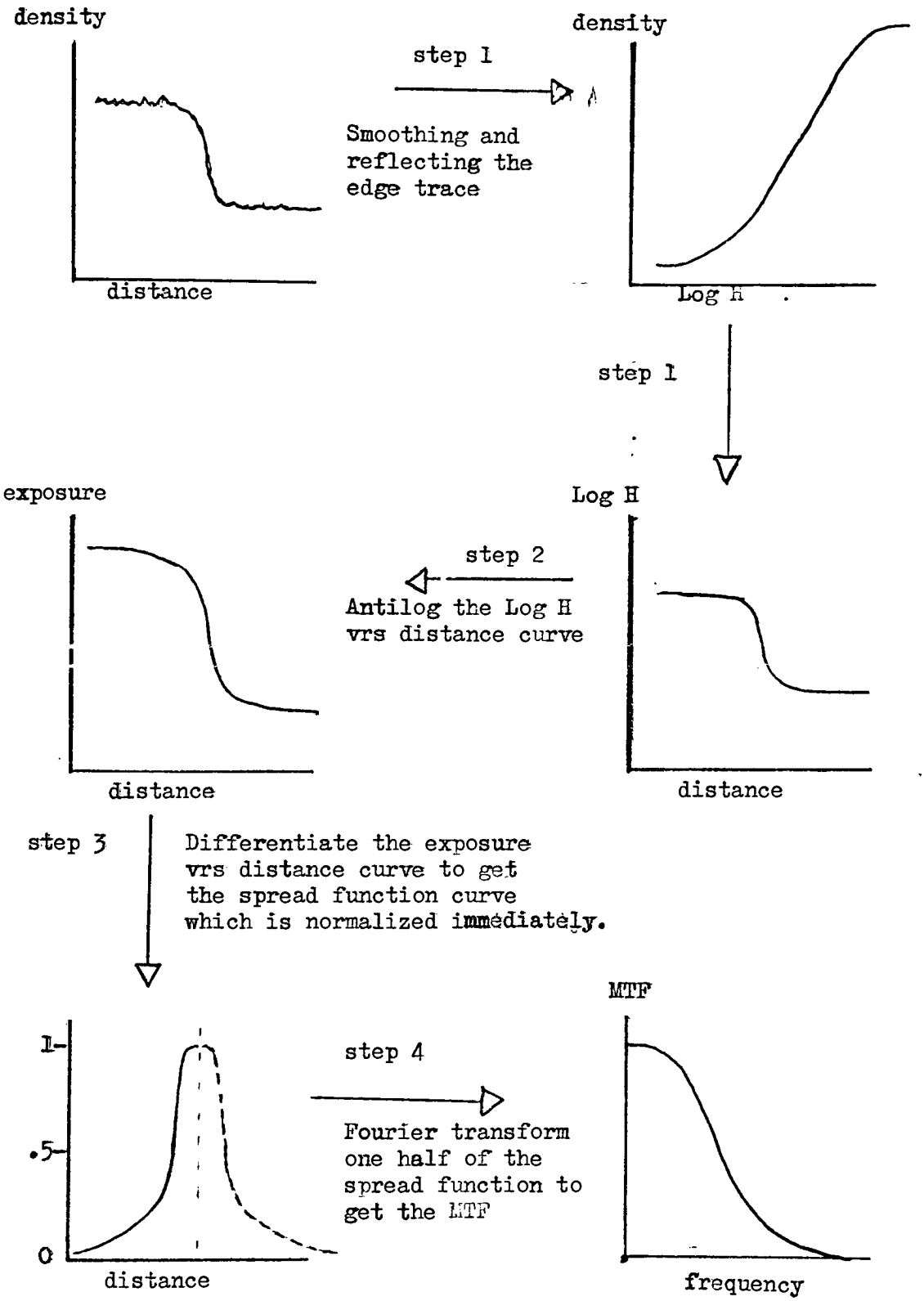
density
distance
step 1
Smoothing and
reflecting the
edge trace
density
Log H
step 1
exposure
distance
step 2
Antilog the Log H
vrs distance curve
Log H
distance
step 3
Differentiate the exposure
vrs distance curve to get
the spread function curve
which is normalized immediately.
1
.5
0
distance
step 4
Fourier transform
one half of the
spread function to
get the MTF
MTF
frequency

Figure 1

RESULTS AND CONCLUSIONS

Measurements of image quality according to Table 3 and Figure 2 through Figure 5 for each development process indicate a significant increase of image quality with the PPD prefixation physical developer on the Eastman 5302 fine grain emulsion for both resolving power and MTF. There was a significant decrease in resolving power and MTF for Matejec's postfixation developer when used with the 5302 film. It is interesting to note the change in the shape of the MTF curve for this film-developer combination. This would indicate that the grain size distribution in the film was one of much larger and more uniform grains than the other processes produced with 5302 film.

Of the other film-developer combinations tested, PPD postfixation developer with 5302, and PPD prefixation developer with Panatomic-x, there was no significant change in image quality when compared to the same films chemically developed.

	5302	Panatomic-x
Chemical Development	91.5	72.6
PPD Prefixation Physical Development	138.5	81.5
PPD Postfixation Physical Development	121.5	--
Matejec's Postfixation Physical Development	48.3	--

Mean Values of Resolving Power
Table 3

An estimate of the standard deviation of resolving power, s, was taken from a sample size of n=3.

$s = 12.968$

With 5% risk of being wrong when significance is found, $\alpha = .05$ Hypothesis testing was used to check for significant increases or decreases in resolving power relative to chemical development. Using the Table of Significant Levels of t, the test statistic, to find a significant change, t must be greater than 2.92.[13]

$$t = \frac{x-u}{s}$$

where t is the test statistic, x is the point estimate of the combination to be tested (the mean values from Table 3) and u is the estimated mean of the chemically developed film resolving power.

For 5302 PPD prefixation physical development testing for a significant increase in resolving power, t = 3.62,

which is greater than 2.92. Therefore there is a significant increase in resolving power.

For 5302 with PPD postfixation physical development testing for a significant increase, t = 2.31, which is less than 2.92. Thereforethere is no significant increase in resolving power.

For 5302 with Matejec's postfixation physical development testing for a significant decrease in resolving power, t = 3.33. This is greater than 2.92 therefore there is a significant decrease in resolving power.

For Panatomic-x with PPD prefixation physical development testing for a significant increase in resolving power, t = .686. This is less than 2.92; therefore there is no significant increase in resolving power.

In future work it would be of much interest to investigate the dye inhibition reaction of Panatomic-x film with both postfixation processes.

The MTF curves shown all contain the MTF of the microdensitometer. From the Chemical Spread MTF Curves the effect of the difference in the chemical spreads can be seen while in the System Spreads MTF Curves it appears that the optical spread is more significant than the chemical spread in that all of the MTF curves for each film are very close to the same shape.

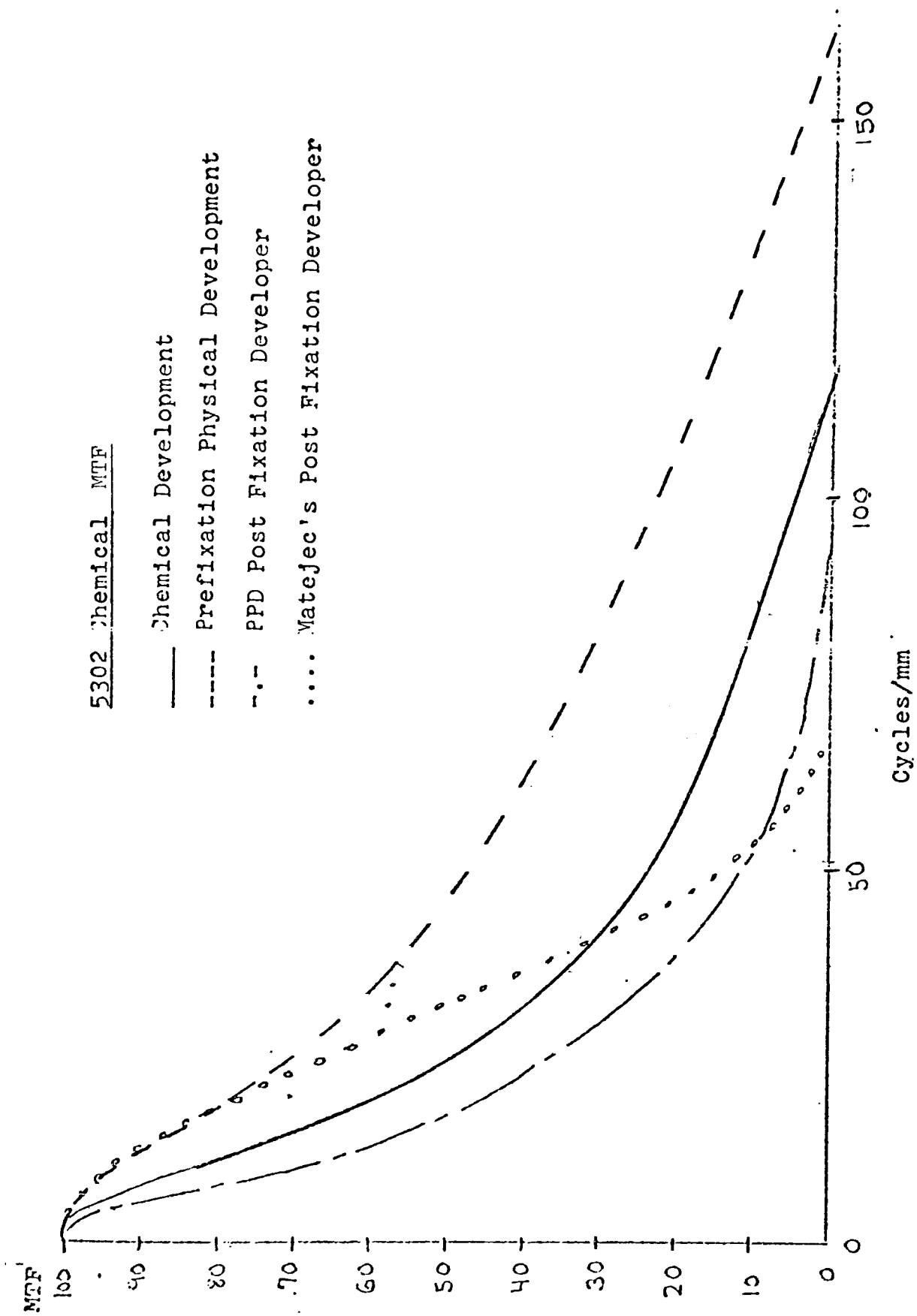
5302 Chemical MTF
Chemical Development
Prefixation Physical Development
PPD Post Fixation Developer
Matejec's Post Fixation Developer
MTF
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
Cycles/mm

Figure 2

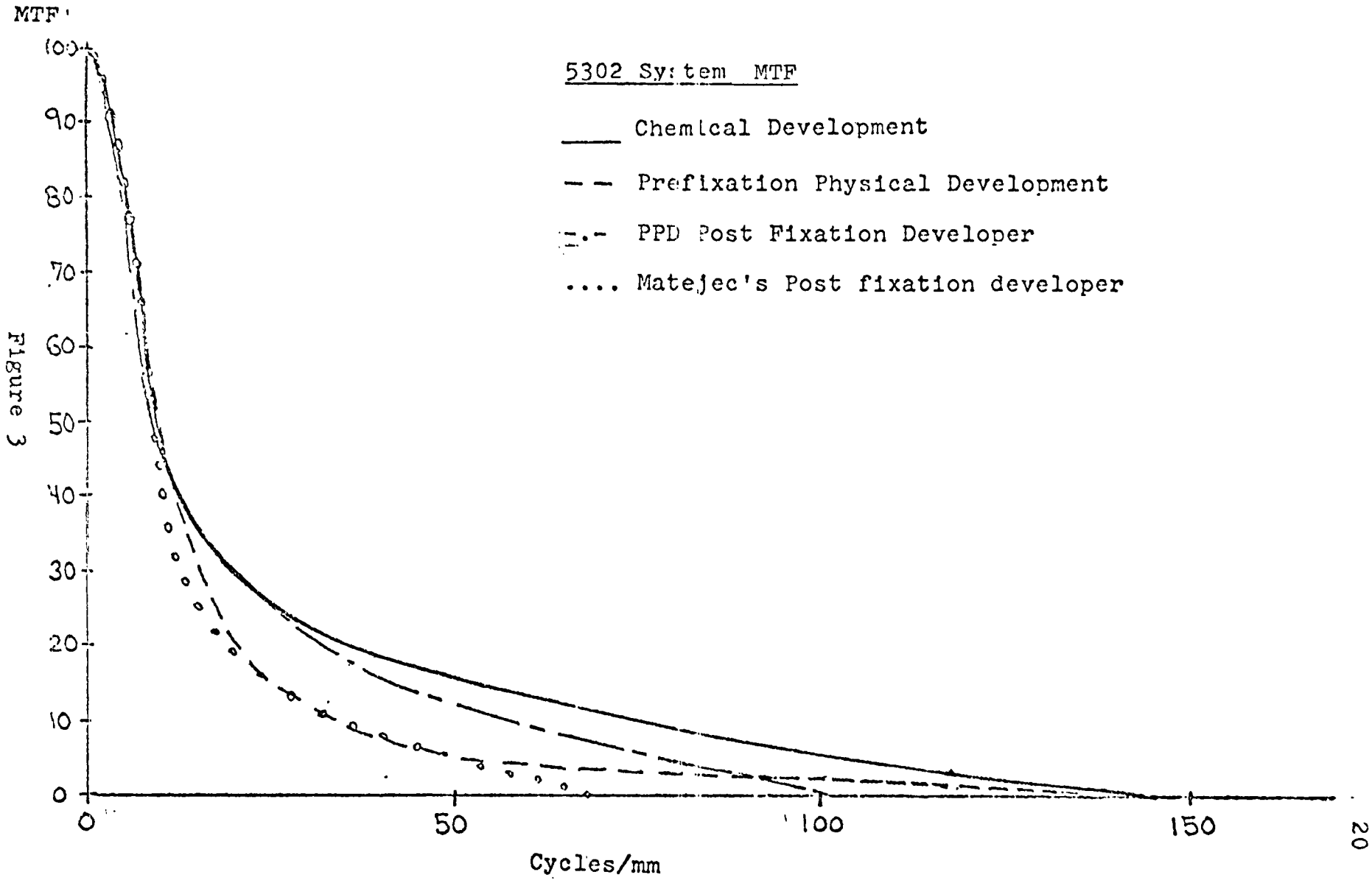
MTF
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
20
Cycles/mm
5302 System MTF
Chemical Development
Prefixation Physical Development
PPD Post Fixation Developer
Matejec's Post fixation developer

Figure 3

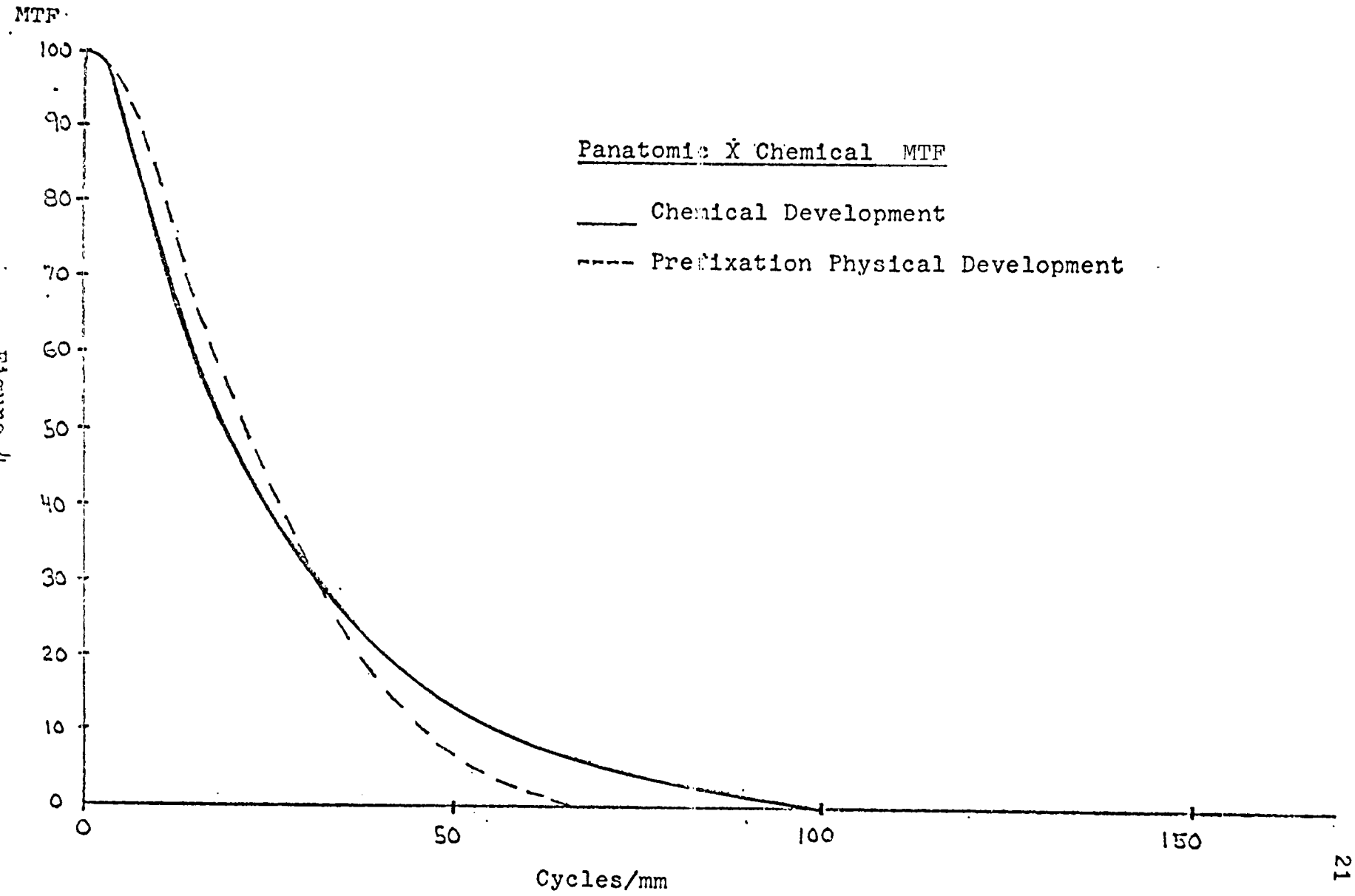
MTF
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
Cycles/mm
Panatomic X Chemical MTF
Chemical Development
Prefixation Physical Development

Figure 4

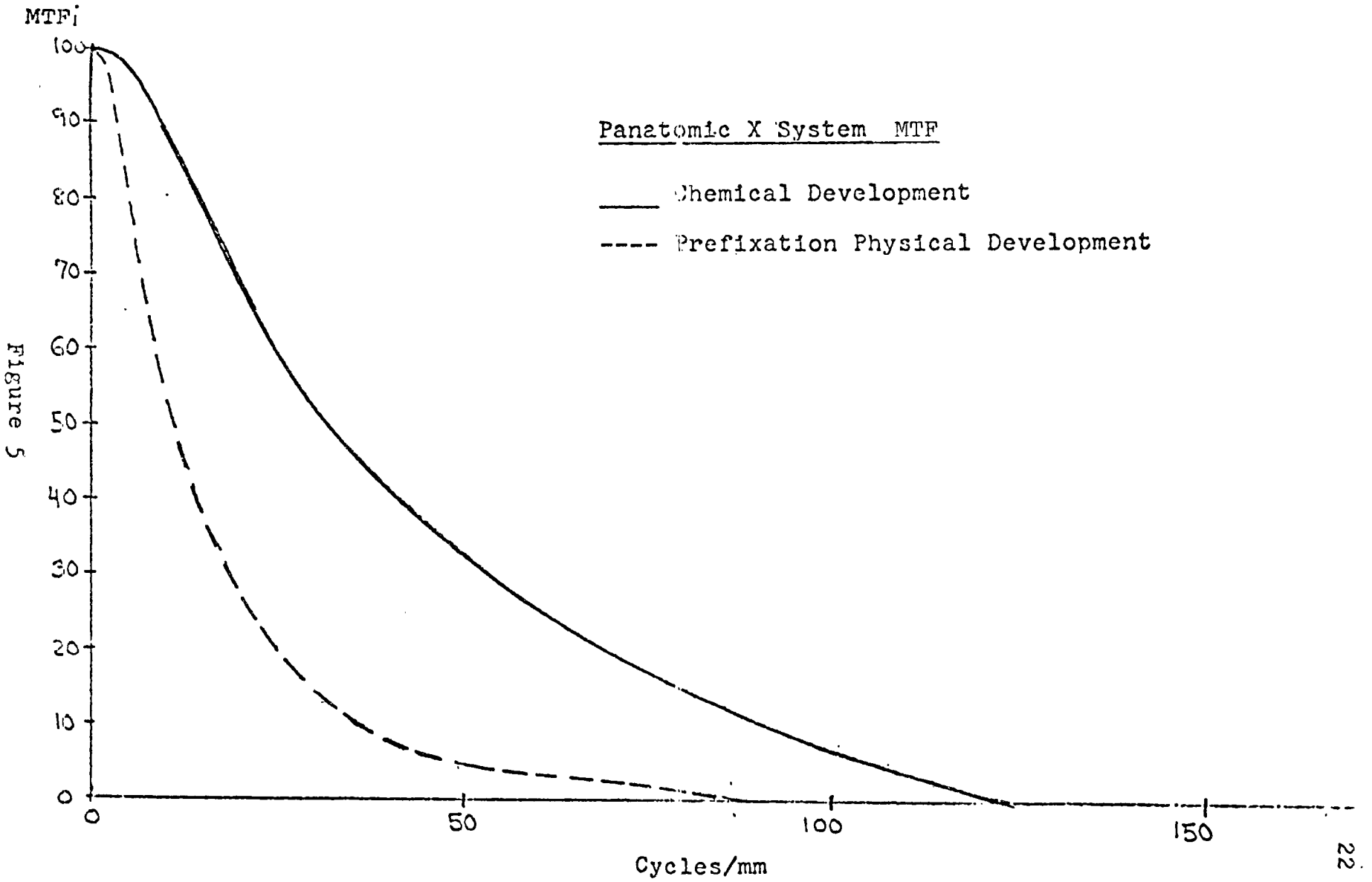
MTFi
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
Cycles/mm
Panatomic X System MTF
Chemical Development
Prefixation Physical Development

Figure 5

FOOTNOTES

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6. C. N. Nelson, F. C. Eisen and G. C. Higgins, "Effect of Nonlinearities When Applying Modulation Transfer Techniques to Photographic Systems," paper presented at the S. P. I. E. Seminar, March 21-22, 1968, Boston, Mass.

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13. Rickmers and Todd, Statistics: An Introduction, New York, 1967, Table A-2, Chapters 1,2,3.

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