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Contrast Index

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Gamma, the slope of the straight-line portion of the *D*-log *E* curve, is not always an appropriate basis for selecting proper development times for photographic films. It often fails when applied to films for which the *D*-log *E* curves have unusually long or unusually short toes because it does not take into account the fact that a portion of the toe of the curve is normally involved in the exposure of a typical negative. The optimum development time is actually the time required to produce a certain average gradient (which depends on the class of photographic work being done) measured over the *used* part of the curve. A new form of average gradient called "contrast index" is described, which is measured over the part of the curve commonly used in practice for continuous-tone, black-and-white, negative and positive films and plates. It is recommended as an aid in determining development times for many of these materials. Gamma will continue to be appropriate for use with the few films and plates that are normally exposed so that the image is recorded wholly on the straight-line region of the curve. A meter that facilitates the measurement of contrast index is described.

Gamma

Gamma, the slope of the straight-line portion of the *D*-log *E* curve of a photographic material, is the traditional basis for choosing development times for photographic materials. Beginning with the studies of Hurter and Driffield reported in 1890, the development of negative and positive films and plates usually has been based on "development to a specified gamma." The gamma value chosen for this purpose is normally different for each class of photographic work.

By means of practical tests with appropriate films, the optimum gamma is first established for each class of work. This value of gamma is then adopted as the criterion for determining the proper development time for any film that may be used for the same application. The development time for each film is selected from the gamma vs. development-time curve which applies to that film for the chosen conditions of development, i.e., developer, developer temperature, and method of agitation. A gamma of 0.65–0.70, for example, is ordinarily considered appropriate for black-and-white portrait films and for black-and-white films used in amateur photography, whereas a gamma of 2.0–2.5 is normally adopted for black-and-white positive films used to make positive transparencies. For some purposes in graphic arts work, a gamma of 1.0 is appropriate.

The use of gamma as a basis for selecting development times for such a wide variety of films and applications is not always satisfactory. It probably would be completely successful if all films and plates were alike with respect to the shape and length of the toe of their *D*-log *E* curves, or if the exposure level were always such that the image would be recorded wholly on the straight-line portion of the *D*-log *E* curve. The shape and length of the toe of the curve are, however, not the same for different types of photographic films and plates and, for most photographic applications, the best quality is obtained in the final print when the exposure is so chosen that the image is recorded partly on the toe and partly on the straight-line portion of the *D*-log *E* curve. Since gamma does not take into account the toe, it frequently fails to indicate the optimum development time. The error becomes noticeable whenever the toe of the curve is unusually long or short.

In Fig. 1 are shown *D*-log *E* curves for two portrait-type negative films. The photographic speed of the two materials is about the same, but the curve for Film B has a significantly longer toe than the curve for Film A. The curves also show that the two films have been developed to yield equal values of gamma (0.65). If a typical camera image were recorded on the two films at an exposure time that will produce a minimum density of about 0.10, the density range of the negatives would be 1.0 on Film A and 0.78 on Film B. A density range of 1.0 is appropriate for a negative that will be used with a medium-grade (Grade 2) photographic paper, if the negative is printed in an average enlarger having an average specularity factor and average stray-light characteristics. For Film A, development to a gamma of 0.65 produces the desired density range. However, developing Film

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B to a gamma of 0.65 produces a negative having a short density range. The resulting print, made on a medium-grade paper, would be too low in contrast or too "flat." One possible remedy is to increase the camera exposure of Film B to record the camera image mainly on the straight-line portion of the *D*-log *E* curve. Such an increase, however, would be equivalent to a loss in effective film speed. Since the average density of the negative would increase, print graininess would also increase. Furthermore, the printing time of such a negative would be considerably longer.

An alternative remedy is to select a paper of higher contrast, a Grade 3 or 4, to produce from the

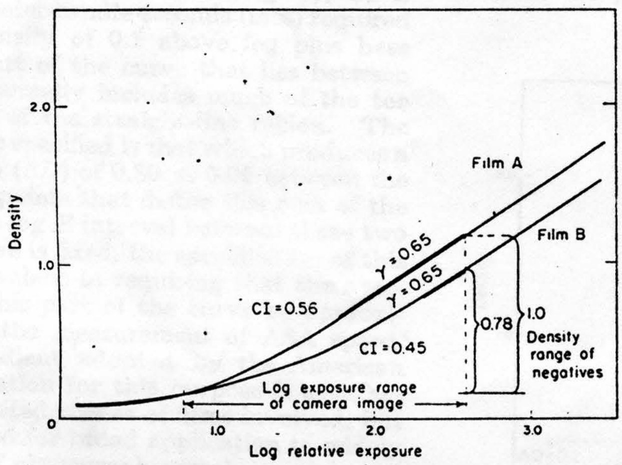

Fig. 1. *D*-log *E* curves for two films that have been developed to equal gammas (0.65). A negative made with normal camera exposure on Film A (medium toe) has a satisfactory density range and produces a print of good quality. A negative made with normal camera exposure on Film B (long toe) has too short a density range for normal printing procedures.

negative made on Film B a print having a density range similar to that of the print obtained on a medium-grade paper from the negative on Film A when it is normally exposed and developed. The printing exposure time is extremely critical, however, with a high-contrast paper and most workers therefore prefer not to use such a paper.

The best remedy is to increase the development time of the negative to obtain a suitable density range, average gradient, and average density, thereby keeping print graininess to a minimum, preserving effective film speed, and permitting the use of a medium-grade paper.

It is apparent that a film having a toe even shorter than that illustrated by Curve A in Fig. 1 would, if developed to a normal gamma of 0.65, produce a negative having an excessive density range. The density range would be greater than that which would be required if the negative were printed on a medium-grade paper.

Average Gradient

Experience has shown that it is necessary to develop continuous-tone negative materials having different curve shapes to a certain *average gradient** rather than to a certain gamma, if the negatives of an average subject are to be printed on the same, medium-grade paper. The average gradient should, of course, be measured over the used part of the curve. This development criterion is especially important if the prints are to be made on a photographic paper that is available in only one contrast grade.

In Fig. 2, the time of development for the negative material, Film B, has been adjusted so that the density range of the negative will be equal to that of the negative made on Film A. The curves no longer have the same value of gamma. Although the curve for Film A has a gamma of 0.65, the curve for Film B now has a gamma of 0.86. It is evident, however, that the average gradient measured over the log exposure interval representing the camera image, is equal for the two curves. Equal density ranges correspond, of course, to equal average gradients when the log *E* interval remains constant. The two negatives can be printed satisfactorily on the same grade of photographic paper. The resulting prints will not be identical in tone reproduction but, if the grade of paper is appropriate and the subject matter is typical of that found in continuous-tone photography, each print will have the best quality that can be obtained by varying only the development time of the negative and the exposure time of the print. It is assumed that the

* The average gradient of a segment of a curve can be thought of either as the slope of a straight line joining the two end points of the segment or as the average of the localized gradients or slopes measured at a series of points (equally spaced in abscissa values) along the segment of the curve. The two methods of determining average gradient give the same results and are mathematically equivalent.

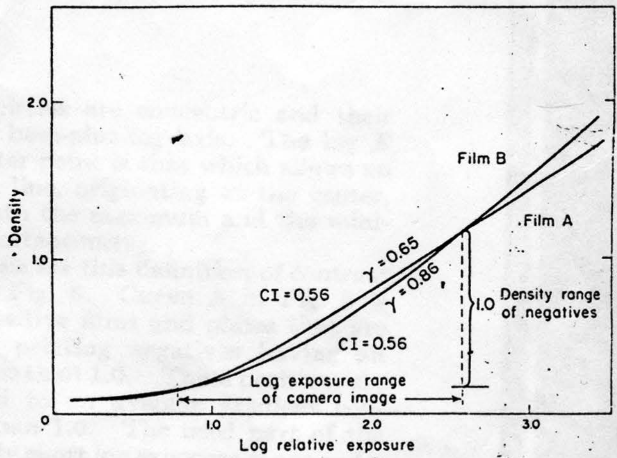

Fig. 2. *D*-log *E* curves for Films A and B (Fig. 1) for times of development adjusted to produce negatives that, for normal camera exposures, will have equal density ranges. The average gradients of the used portions of the curves are equal. The gammas are unequal.

films and developers chosen for this example are used.

The Average Gradient Used in American Standard PH2.5-1960

The American Standards Association[1] specifies the use of an average gradient, in place of gamma, as the basis for choosing the correct development times for determining the speed of negative black-and-white sheet films and roll films for pictorial photography. This average gradient is measured over the part of the *D*-log *E* curve that lies between two exposures, E_m and 20 E_m (E_n) (Fig. 3); E_m is the exposure in meter-candle-seconds (mcs) required to produce a density of 0.1 above fog plus base density. The part of the curve that lies between E_m and 20 E_m normally includes much of the toe region and some of the straight-line region. The development time specified is that which produces a density difference (ΔD) of 0.80 $\pm$ 0.05 between the upper and lower points that define this part of the curve. Since the log E interval between these two points on the curve is fixed, the specification of this ΔD value is equivalent to requiring that the average gradient of this part of the curve be approximately 0.62, for the measurement of ASA speed. The average gradient adopted by the American Standards Association for this purpose is satisfactory for the restricted classes of films involved, but it was not designed for broad application to widely different classes of photographic work.

Definition of Contrast Index (CI)

A new type of average gradient, called "contrast index," is proposed which, for the films covered by the American Standard just discussed, is compatible with, and essentially equivalent to, the average gradient specified by the Standard. Contrast index has the advantage, however, that it applies to a broader range of films and plates and to many types of photography.

Contrast index is defined as the average gradient of the part of the *D*-log *E* curve lying between two points that represent the maximum and minimum densities illustrated in Fig. 4. The minimum densities lie on the arc of a circle having a radius of 0.2 in density or log exposure units. The maximum density lies on the arc of a circle having a radius 2.0 greater than the radius of the smaller circle. The two circles are concentric and their center lies on the base-plus-fog axis. The log E position of the center point is that which allows an imaginary straight line, originating at the center, to pass through both the maximum and the minimum densities simultaneously.

The practical basis for this definition of contrast index is shown in Fig. 5. Curve A in Fig. 5 is typical of many positive films and plates that are ordinarily used in printing negatives having an average gradient less than 1.0. These positives are normally developed to an average gradient considerably greater than 1.0. The used part of the curve has a relatively short log exposure range and a relatively long density range. The minimum densities in the positives usually lie between 0.15 and 0.30 above fog-plus-base density. The maximum densities usually lie between 1.8 and 2.1 above fog-plus-base density.

Curve B in Fig. 5 is typical of films used in some continuous-tone work in graphic arts. The aver-

1. American Standard Method for Determining Speed of Photographic Negative Materials (Monochrome, Continuous-Tone), PH2.5-1960.

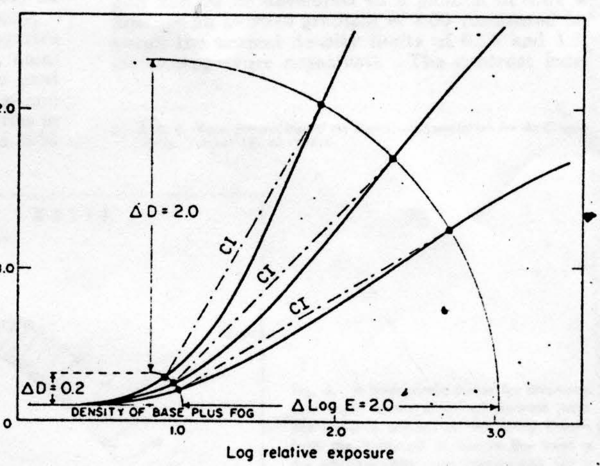

Fig. 4. Contrast index (CI) is the slope of a straight line joining selected minimum and maximum densities on the *D*-log *E* curve. The minimum density lies on the arc of a circle having a radius of 0.2 in density units. The maximum density lies on the arc of a larger circle concentric to the smaller one and having a radius 2.0 greater than that of the smaller circle.

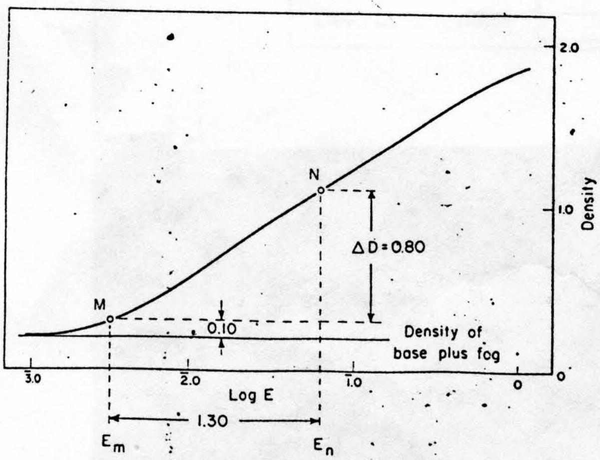

Fig. 3. The American Standard method of choosing the development time for film-speed determination. Development to a ΔD interval of 0.80 (for the log E interval of 1.3) is equivalent to developing to a specified average gradient.

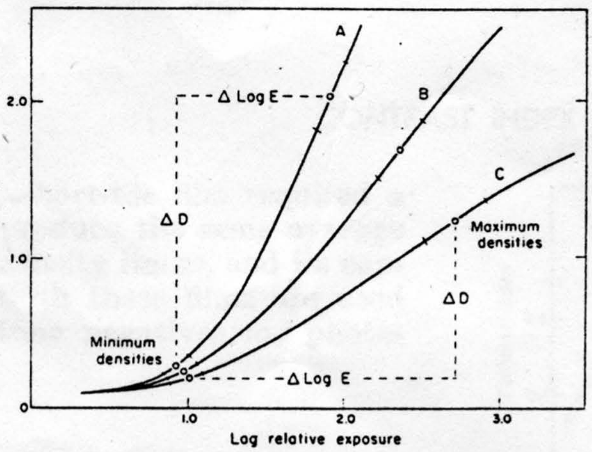

Fig. 5. The maximum and minimum densities in practical negatives and in film positives are commonly found to lie on their *D*-log *E* curves in the regions shown in this graph. When the density range is large, the log *E* range is usually small; and vice versa.

age slope of the curve is about 1.0. The log exposure range and the density range of the used part of the curve are nearly equal. The minimum densities often lie between 0.1 and 0.2 above fog-plus-base density. The maximum densities usually lie between 1.4 and 1.8 above fog-plus-base density.

Curve C in Fig. 5 is typical of most negative materials intended for portrait, commercial, amateur, and motion-picture photography. The used part of the curve has a long log exposure range and a short density range. The minimum densities in the negatives usually lie between 0.05 and 0.15 above fog-plus-base density. The maximum densities lie between 1.0 and 1.4 above fog-plus-base density.

It is evident from these data that, as the log exposure range of the normally used part of the curve decreases, the average gradient, density range, and minimum and maximum densities increase. The minimum densities tend to fall on the arc of a small circle and the maximum densities tend to fall on the arc of a larger circle. These general features of photographic practice are taken into account by contrast index.

The basic concept of contrast index was introduced in 1961 at a meeting of the Technical Association for the Graphic Arts.[2] At that time it appeared that the simpler form, employing a constant minimum density of 0.15 above fog-plus-base density, would be satisfactory. Subsequent work has, however, shown that the estimates of development time resulting from the present definition of contrast index are sufficiently improved to justify the change.

Certain films for the graphic arts provide extreme examples of the failure of gamma as a criterion of contrast. In particular, the so-called commercial films have such long toes that the gamma often has to be measured at a density of 2 or more—far above the useful range. In one case, a commercial film had to be developed to a gamma of 1.81 to produce an average gradient of 1.00 (measured between the normal density limits of 0.25 and 1.55 for photogravure negatives). The contrast index

2. J. A. C. Yule, *Proceedings of the Technical Association for the Graphic Arts* (*TAGA*) 13: 43 (1961).

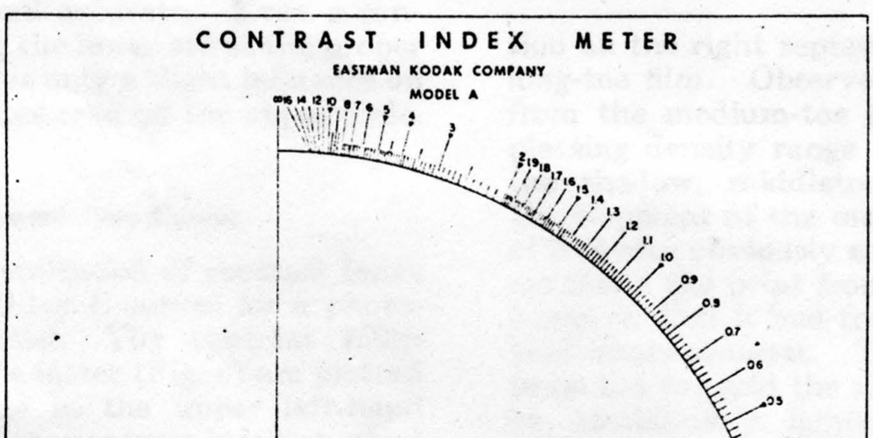

Fig. 6. A transparent meter for convenient and rapid measurement of contrast index. The meter is placed on the *D*-log *E* curve (with the indicated horizontal line kept on the base-plus-fog axis) and moved left or right until the curve intersects the upper and lower arcs at equal numbers on the two scales.

was 1.01. A particular, short-toe film required a gamma of only 1.11 to produce the same average gradient, between these density limits, and its contrast index was 1.01. Both these films are used for making continuous-tone negatives for photogravure.

A Contrast-Index Meter

A meter which greatly simplifies the measurement of contrast index is illustrated in Fig. 6. The meter is a transparency which is used by placing it on the *D*-log *E* curve with its fog-plus-base line set on the fog-plus-base density of the curve. The horizontal lines of the meter are kept parallel to the log *E* axis of the graph, while the meter is moved to the right or to the left until the lower arc intersects the toe of the *D*-log *E* curve at a number (shown on the small arc) equal to the contrast-index number found at the intersection of the curve with the upper arc. The contrast-index value is then read from the numerical scale on the upper arc.

Experience with the meter has shown that this method is convenient and accurate. Even a considerable error in setting the lower arc at the proper toe point on the curve has only a slight influence on the value of contrast index read off the upper scale.

Contrast-Index vs. Development-Time Curves

Figure 7 shows the application of contrast index to a typical family of *D*-log *E* curves for a photographic negative material. The contrast index values measured with the meter (Fig. 6) are plotted against *development time* in the upper left-hand corner of the graph. If the contrast index required for a certain class of photographic work with this film is known (or can be determined by preliminary practical tests), the appropriate development time can be selected from the contrast-index vs. development-time curve.

Of course, the composition of the developer, the temperature, and the degree of agitation of the developer must also be under good control if the results are to be meaningful in any critical application.

Pictorial Demonstration

Figure 8 shows halftone reproductions of photographic prints made on a medium-grade photographic paper from two negatives, differing in toe length, that were developed to the same *gamma* (0.65). Although the halftone reproductions may not show accurately the large differences that existed in the appearance of the original photographic prints, they probably illustrate adequately the nature of the failure of gamma as a criterion of development time when the negative materials differ in toe length.

The reproduction on the left represents the print made from the medium-toe film and the reproduction on the right represents the print made from a long-toe film. Observers who examined the print from the medium-toe film decided that it had a pleasing density range and good tonal contrast in the shadow, middletone, and highlight regions. Development of the medium-toe film to a gamma of 0.65 was obviously satisfactory. Observers who examined the print from the long-toe film decided, however, that it had too short a density range and inadequate contrast. The highlight region was said to be too flat and the shadow areas were judged to be considerably lighter than the corresponding areas of the original scene. Development of the long-toe film to the same gamma of 0.65 was definitely unsatisfactory. The *D*-log *E* curves for the two films are those of Fig. 1.

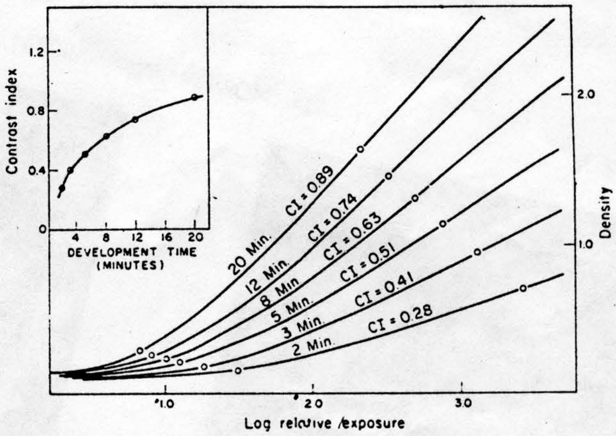

Fig. 7. The application of contrast index to a family of *D*-log *E* curves obtained by developing a negative material for a series of development times. The measured values of contrast index are plotted against development time, in the upper left-hand corner of the figure, and the resulting curve is used in choosing the development time when the contrast index desired for a certain class of work is known.

Figure 9 shows halftone reproductions of photographic prints made on a medium-grade photographic paper from two negatives that were developed to the same contrast index (0.56). The negative materials were those used for Fig. 8. The *D*-log *E* curves are shown in Fig. 2. The reproduction on the left in Fig. 9 was made from the print that involved the medium-toe film; the reproduction on the right was made from the print that involved the long-toe film. Both prints were judged to be satisfactory.

The two prints represented in Fig. 9 are, of course, not identical. They differ in tone reproduction because of the differences in the shapes of the *D*-log *E* curves of the two negative films, but each print has the best tone-reproduction quality that can be obtained by varying only the development time of the negative and the exposure time of the print. The print illustrated on the right has higher contrast in the face tones than the print on the left, because of the relatively high gradient in the upper part of the *D*-log *E* curve of the film with the long toe. The print illustrated on the left has

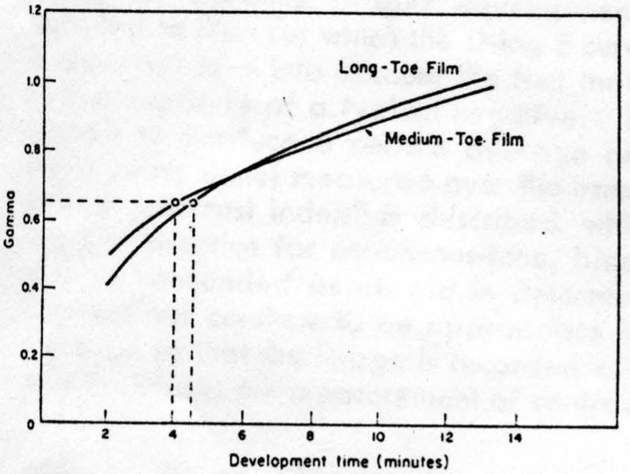

Fig. 10. The gamma vs. time-of-development curves for the two negative films used in making the pictorial demonstration of Figs. 8 and 9. Development times of 4 min and 4⅔ min are indicated by the gamma criterion, but only one of these times is satisfactory pictorially.

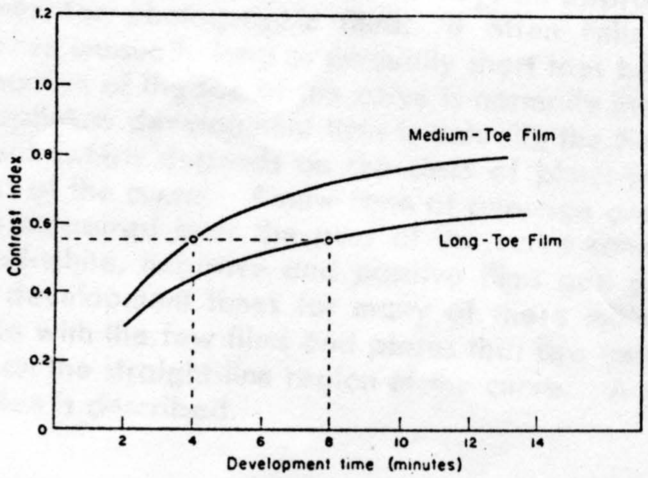

Fig. 11. The contrast-index vs. time-of-development curves for the two negative films used in making the pictorial demonstration of Figs. 8 and 9. The indicated development times of 4 min for the medium-toe film and 8 min for the long-toe film are satisfactory from the standpoint of print quality.

higher contrast in the shadow region, because of the relatively high gradient in the lower part of the D-log E curve of the film having the medium toe. (See the curves of Fig. 2.)

The long-toe film is ordinarily recommended when the photographer wishes, for example, to obtain "brilliance" in the face tone of a portrait or to emphasize highlight detail in commercial-advertising photographs. The medium-toe film is ordinarily recommended for general-purpose photography and especially for photography of subjects in which shadow detail and highlight detail tend to be of equal interest.

Figure 10 shows the gamma vs. time-of-development curves for the two negative films used in making the pictorial demonstration of Fig. 8. If development to a gamma of 0.65 were adopted as the criterion for choosing the development times, then the medium-toe film would be developed for 4 min and the long-toe film for 4⅔ min. The picture tests demonstrated, however, that the long-toe film should be developed for 8 min and the medium-toe film for 4 min (Fig. 9).

Figure 11 shows the contrast index vs. time-of-development curves for the same two materials. Using development to a contrast index of 0.56 (for portrait work) as the criterion for choosing the development times, we arrive at the correct conclusion that the long-toe film should be developed for 8 min and the medium-toe film for 4 min.

Some Exceptions to the Use of Contrast Index

In the majority of photographic applications, the level of exposure is such that much of the toe of the D-log E curve is involved. The use of contrast index is then likely to be advantageous. However, there are certain applications for which a distinctly different level of exposure is required and the use of contrast index is inappropriate. For example, premasks for the 2-stage masking method of color correction are normally exposed so that only the straight-line portion of the D-log E curve is involved. Similarly, in aerial photography at high altitudes, where atmospheric haze greatly reduces the contrast of shadow detail, the preferred exposure time is often greater than that associated with contrast index. Most of the camera image is recorded on the straight-line region so that a further reduction in shadow-detail contrast by the low-gradient part of the toe of the curve will be avoided. For such applications, contrast index is not intended to replace gamma. Certain forms of average gradient that differ from contrast index may be especially suitable for some situations.

The use of contrast index with extremely high contrast materials such as those used in making line or halftone negatives and positives, has not been explored, and it is not intended for use with reversal films or color films.

Development Recommendations Based on Contrast Index

Until recently, recommended development times for Kodak films in rolls and sheets for amateur and professional use were usually based on development to specific values of gamma. Today, many of the development times published for Kodak black-and-white continuous-tone films are based on contrast-index measurements.[3] Data sheets found in new Kodak publications for these products will include time-of-development vs. contrast-index curves.

3. "Contrast Index, A New Yardstick for Development," Kodak Sales Service Pamphlet, F-14, July, 1964, Eastman Kodak Company, Rochester, N. Y., 14650.