Depth of Field in Photomacrography with ZEISS LUMINARS

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by Johannes Fluegge

For photomacrography at magnifications up to 200 X (including any subsequent enlargement of the negative), it is frequently desirable to determine the exact depth of field before exposure. This can be done by employing a mathematical formula which, however, is a rather complex process because of the influence of a number of determining factors which, again, are variables. They are:

1. The focal length of the lens
2. The f-stop used
3. Object-to-image ratio
4. The subsequent enlargement of the negative
5. The distance from which the finished print will be viewed
6. The visual acuity of the observer

Only the last factor can be indicated with certainty provided the observer has normal vision and views the picture under normal light conditions. In the following study an angle of 1.7 minutes of arc has been assumed to represent this factor.

All other factors vary, depending on the lens, the photographic conditions, and the viewing distance. The extent of variability is illustrated in the following:

1. Choice of focal length of the lens, ranging from 16 mm to 100 mm:

   Maximum optical performance of each objective can be expected only for a certain range of magnification, i. e.

Luminar	Maximum performance at	Good performance between
100	2 : 1	0.8 : 1 and 8 : 1
63	3.2 : 1	2 : 1 and 10 : 1
40	5 : 1	4 : 1 and 16 : 1
25	10 : 1	6.3 : 1 and 25 : 1
16	16 : 1	10 : 1 and 40 : 1

   This is especially true if the lenses are used at their largest aperture.

2. F-stop:

   The smaller the lens opening, the greater the depth of field. At the indicator mark 1, the diaphragm is wide open. At this setting the depth of field is at its minimum.

3. Object to-image ratio:

   Applicable ratios are specified in the above table. The depth of field decreases as the magnification increases.

4. Subsequent enlargement of the negative:

   The more a negative is subsequently enlarged, the greater is the loss in depth of field. However, subsequent photographic enlargement does not reduce the depth of field to the same extent as a higher magnification would in the negative. In many cases it is, therefore, preferable to take the photograph at a relatively small magnification and make a photographic enlargement to obtain a print of sufficient size at the least loss in depth of field.

5. Appropriate viewing distance (observer to print):

   At a short viewing distance (normally 10″ = ¼ meter), the depth of field is less than at larger distances, as, for instance, in the case of photo-murals.

The nomogram on the opposite page has been drawn up to determine depth of field quickly in spite of the many factors involved.

The nomogram is devided into five sections marked A, B, C, D, and K.

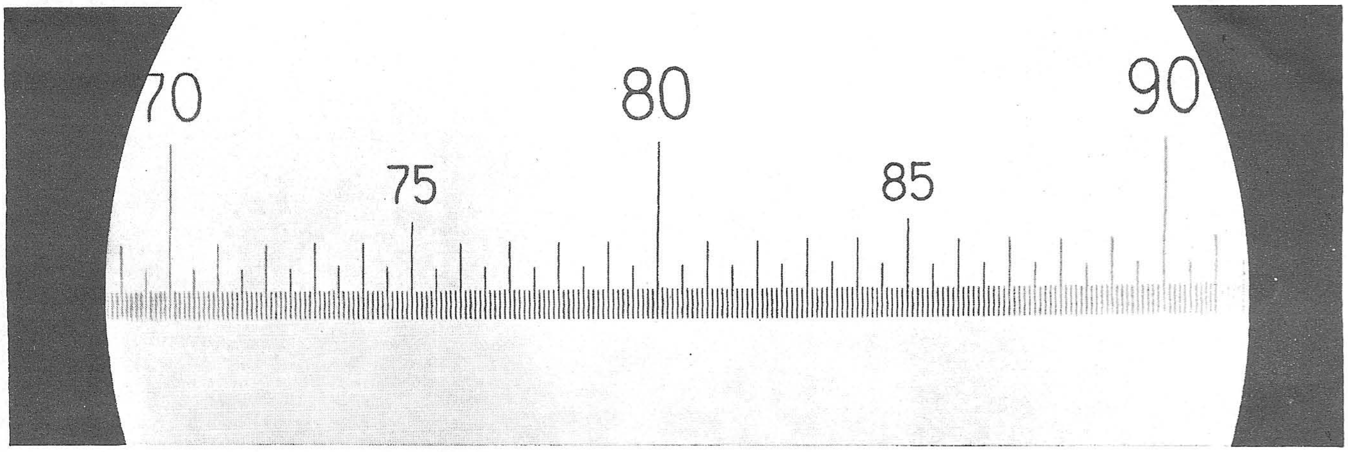
Section A: Four vertical columns with f-stop numbers (1, 2, 4 . . . 30) for the various LUMINARS. The f-stops are marked by points.

Section B: Parallel diagonal lines for several object-to-image ratios (in geometric progression).

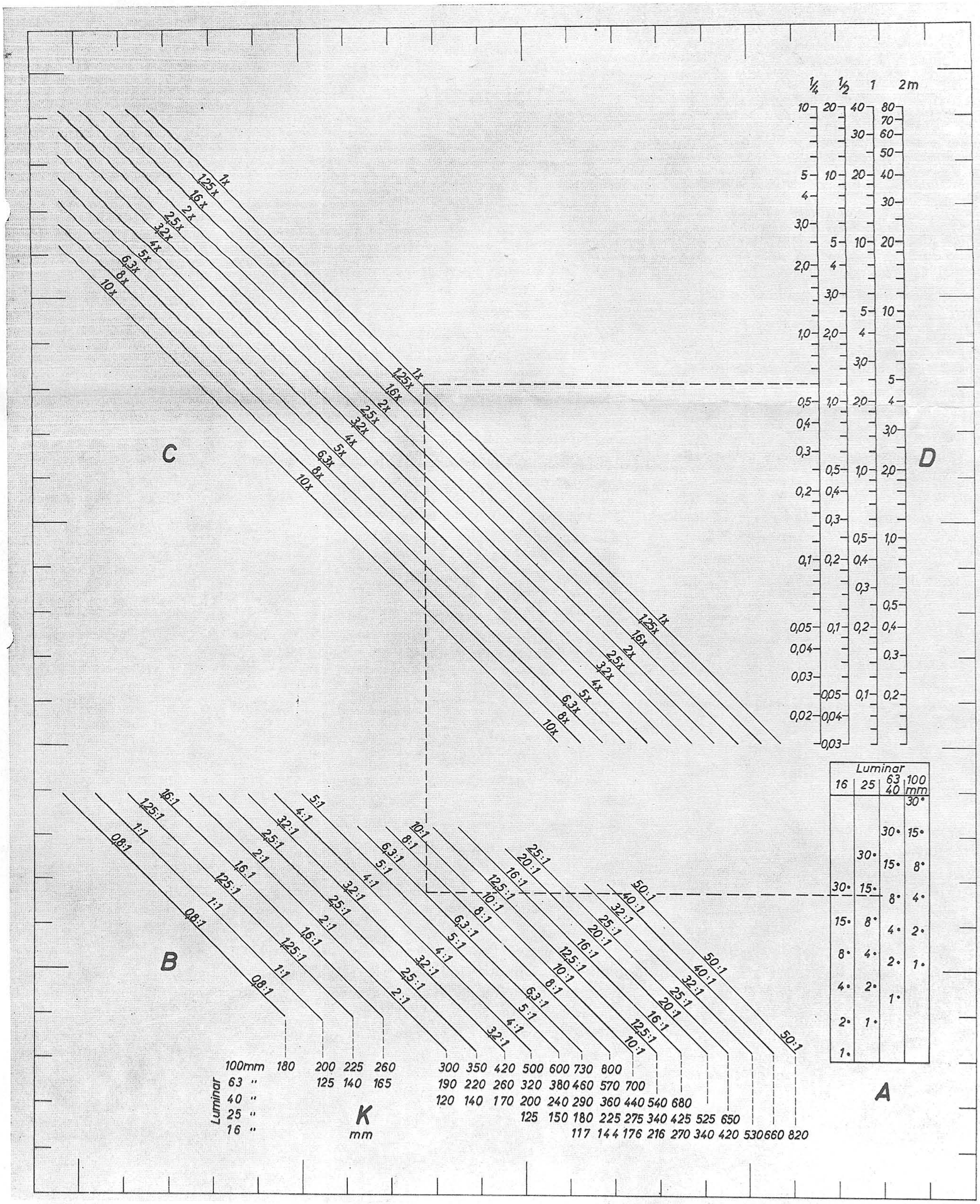
Section C: Parallel diagonal lines for several subsequent photographic enlargement factors (in geometric progression).

Section D: Four columns for depth of field (in millimeters). The column headings represent the viewing distance from observer to print.

Section K: Various bellows extensions (distance between diaphragm ring of the lens and film plane), are listed for the different available LUMINARS.



Photomacrograph of a scale graduated in tenth of millimeters taken according to the data in the first example. The scale was placed in an oblique position so that there was 0.1 mm difference of depth for 1 mm on the scale (e. g. 80 – 81). The depth of field on the photo ranges from 77 to 83 and thus amounts to 0.6 mm. Unfortunately, the printed picture does not show this as clearly as the original photograph. (Photo: Dr. F. K. Moellring, CARL ZEISS, Oberkochen).



How to use the chart

The broken lines in the nomogram illustrate examples one and two.

Example I

The following photographic data are given:

A: LUMINAR 40 mm, f-stop 8

B: Bellows extension of K = 290 mm. The figure 290 is found in section K for the LUMINAR 40. When the line above the figure 290 is followed, it will lead to the beginning of the diagonal line marked 6.3 : 1. This is the object-to-image ratio.

C: For contact printing, that is, no enlargement, the enlargement factor is 1 x.

What will the depth of field be if the print is viewed from a distance of 10″ (¼ meter)?

From section A draw a horizontal line from point 8 in column 40 to the left until you meet the diagonal 6.3 in section B. Then go straight up to the diagonal line marked 1 x in section C, and finally move horizontally to the right until you hit the ¼ column in section D which stands for 10″ distance. At this point the reading for the depth of field is 0.6 mm.

Example II

The following data are given:

A: LUMINAR 40 mm, f-stop yet to be determined

B: As in previous example

C: As in previous example

D: Desired depth of field = 0.6 mm

To what aperture should the LUMINAR be stopped down?

The procedure is in principle analogous to that used in the first example. Only the sequence of steps is different, from D to C, B, and A. Following the line, one arrives at figure 8 for the f-stop in the column for LUMINAR 40 mm.

Example III
(not marked in nomogram)

The following data are given:

Let the desired depth of field be 3.0 mm at a normal viewing distance of 10″ (¼ meter). The final print should be enlarged as much as possible.

Which lens, scale of magnification and enlargement factor should be used?

To answer this question it is necessary to check a few possibilities on the chart. The starting point is in section D, figure 3.0 under the heading ¼ m. From here a line is first drawn horizontally to the left. The points of intersection are marked on two of the diagonals in section C, for example on the diagonals 1 x (contact print) and 8 x (enlargement). From each of these points draw a line straight down until you hit a diagonal in section B for the first time. From the diagonal 1 x in section C, you arrive at diagonal 3.2 : 1. Thus, the magnification ratio would be 3.2 x for the final print. Moving downward from the diagonal 8 x in section C, you hit the diagonal 0.8. If you mutiply 0.8 by 8 x, you obtain a total enlargement figure of 6.4.

A greater enlargement is derived through the second possibility. Therefore this case should be chosen for the given problem.

From the point of touch on diagonal 0.8 : 1, a horizontal line is drawn towards the right, to section A, where an f-stop value of 30 is found for the LUMINAR 100. The bellows extension for this objective is found in the LUMINAR 100 line (first line in section K) by following the diagonal 0.8 : 1 downwards. This line ends above the value 180, which stands for the bellows extension in millimeters. Summing up, the desired depth of field of 3 mm at a viewing distance of 10″ (¼ meter) can be achieved by using a LUMINAR 100 at f/30, a bellows extension of 180 mm, a corresponding working distance (9″ = 225 mm) and by enlarging the negative photographically 8 x so that the final print will show a total ratio of magnification of 6.4 : 1. Under these extreme conditions it is, of course, necessary to use a fine-grain film, fine-grain developer and an enlarger with high-quality optics.

It seems odd that in this case the highest total magnification is obtained when first reducing the object on the film (0.8 : 1)! The example given illustrates this very strikingly. It confirms the general rule that low magnifications and greater subsequent enlargement lead to a greater depth of field. This can also be proven by a variation of the first example in which the object-to-image ratio was 6.3 : 1, the enlargement factor 1 x and the total magnification of the print 6.3 : 1. However, if the negative were taken at a magnification of 2 : 1 and subsequently enlarged 3.2 x, the depth of field would reach almost 0.8 mm (as compared to 0.6 mm in example one).

In order not to lose a desired depth of field, magnifications cannot exceed a certain value.

Example IV

The fact that high total magnification reduces the depth of field is also evident from the chart.

For example, a 25 x magnification on the film (using a LUMINAR 16 at f/30) and subsequent enlargement 4 x (i. e. a total magnification of 100 x) will result in a depth of field of barely 0.04 mm at a viewing distance of 10″ (¼ meter)!

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