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The effect of chromatic aberration in process lenses on the copying of reflection halftone dots

Burdette A. Saunders

THE EFFECT OF CHROMATIC ABERRATION IN PROCESS LENSES ON THE COPYING OF REFLECTION HALFTONE DOTS

by

Burdette A. Saunders

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photography in the College of Graphic Arts and Photography of the Rochester Institute of Technology.

June 1972

Thesis adviser: Dr. G. W. Schumann

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THE EFFECT OF CHROMATIC ABERRATION IN PROCESS LENSES ON THE COPYING OF REFLECTION HALFTONE DOTS

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An Abstract

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A method for evaluation of copydot quality is determined. This method is applied to the problem of determining the relative copydot quality of two films of different spectral sensitivities, while using two process lenses with measureable amounts of chromatic aberration.

OBJECTIVES

In this paper I shall attempt to answer the following questions:

Is there a difference in optimum lens position for copydot when using

(1) a blue sensitive film
(2) an orthochromatic film with
    (a) a green filter
    (b) a blue filter
    (c) no filter

in combination with two process lenses?

If so, how big are the differences?

Which lens has the larger chromatic difference of focus?

Which lens has the larger practical depth of focus?

Is there a difference in copydot quality among the above lens-film-filter combinations?

Which film is best for copying dots?

Which film is least sensitive to defocus?

BACKGROUND

The Problem

It has been observed that process camera focus depends on the illuminant and the spectral sensitivity of the film. Although process lenses are usually classified as achromatic or apochromatic, little is published on the actual degree of the chromatic error and its effect on film performance.

It is interesting to note that the use of lithographic films often makes sharp focusing unnecessary. Indeed, sometimes it is actually undesirable. A particularly critical situation is found when the original has a dot structure and it is desired to maintain the structure and dot size integrity during reproduction. The results of this effort depend on both camera and film. An experiment intended to compare two films in their ability to copy dots must control the camera variables, or a false conclusion may be drawn.

The copydot situation has been largely ignored in the literature,[1] but arises in practice in these and other situations:

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1. Copy Dot Reproduction, Sellinger, John G., National Lithographer, June 1963.

1. Conversion of letterpress engravings to lithographic plates.

2. Reproducing process color work from singly printed reproduction proofs.

3. Shooting black-and-white negatives from copy or proofs, when the original photograph is not available.

4. Shooting combination line copy and prescreened print pasteups in lithography to circumvent the costly stripping operation.

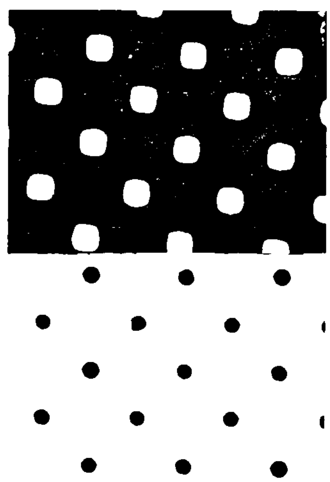
In these critical applications, many variables can affect the quality of the copydot reproduction, such as film type, exposure level, illuminant, camera lens position, f-stop, colored filters, focal surface shape, flare, diffraction, processing effects, and so on. In preliminary experiments, precautions were taken to control these variables, while a technique for measuring relative copydot image quality as a function of focus position was perfected.

The Apparatus

The experimental set-up was as follows. Camera A was a horizontal process camera equipped with an 18-inch apochromatic lens. The target was a reflection test object consisting of three halftones with different screen rulings, a halftone grey scale (120 line/in.), two contour maps, and samples of several type sizes. The target was illuminated with pulsed xenon light sources. The films were a commercially available orthochromatic "lith" film and a commercially available blue-sensitive "contact" film. They were processed in a roller-transport processor in a commercially available developer.

Fig. 1

THE ORIGINAL DOTS



These two steps of the halftone step tablet were selected for analysis because their images on the negatives were of the size range most easily and accurately measureable with the available equipment.

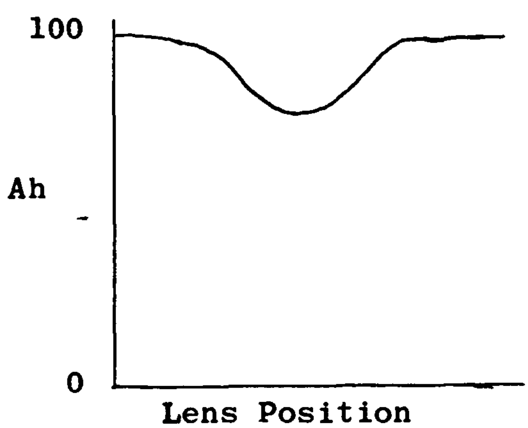
Camera B was a vertical in-darkroom process camera with a 10 3/4-inch achromatic lens. Both lenses were operated at f/16. The target in this case was illuminated with tungsten-halogen lamps. The film was processed in a processor nearly identical to the first, containing the same developer.

Dot areas were measured densitometrically with no fringe correction, using a Kodak densitometer Model 31A, modified to read dot area from 90% to 99.9%, and from 0% to 12%.

The Analytical Technique

It was hypothesized that the relationship of Ah (the area of a selected highlight dot on the negative) to lens position would resemble an inverted gausian:

Fig. 2. Highlight Dot Area Vs. Lens Position



Far out of focus the dark spot projected on the film from a highlight dot would tend to be obscured by general flare light and edge degrading, and in the worst possible case be completely filled in to yield a "plugged" negative with 100% highlight dot area. Closer to optimum focus, the highlight dot would only be partially "plugged," and the size of the dark area on the negative would be somewhere between the ideal size (1-Dot area of original) and 100%.

At optimum focus most real lenses will not produce an ideal-sized highlight or shadow dot. Even under the best conditions there is some degradation so that at best ideal dot size is only approached. The smallest highlight dot area a lens can produce will probably be produced at optimum focus.

This hypothesis appeared to be true; however, the noise level was found to be quite high and the optimum difficult to locate. It was then hypothesized that a similar analysis of shadow dots might be more easily decipherable. Shadow dots should disappear far from otpimum focus and grow to a maximum size at optimum focus,

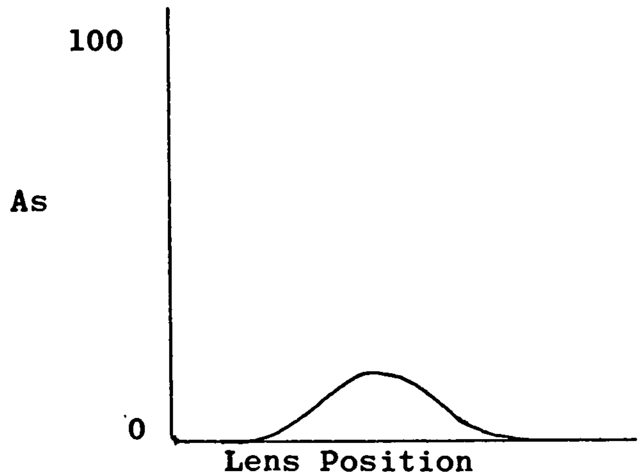


Fig. 3. Shadow Dot Area Vs. Lens Position

by an argument similar to that previously applied to highlight dots.

This relationship, too, was confirmed in preliminary experiments, and as with the highlight dot analysis a high noise level was noted. Plotting the data from both highlight and shadow dot analysis on the same graph, it was noticed that high shadow dot areas were usually accompanied by high highlight dot areas and vice versa. This was interpreted as differences in overall exposure level between sheets of film. To partially remove this effect--to "subtract out neutral density" as it were--a plot was made of (Ah-As) versus lens position.

Far from optimum focus Ah approaches 100% and As approaches 0%, so (Ah-As) approaches 100%. Near optimum focus Ah approaches a minimum, As approaches a maximum, and (Ah-As) approaches a minimum.

As (Ah-As) approaches a minimum, selected highlight and shadow dots become more and more alike in size--the highlight dot becomes less like a pinhole and shrinks (the clear area expands). At the same time, the shadow dot is growing--in other words, (Ah-As) is a measure of inverse scale length; minimizing (Ah-As) maximizes scale length. This will normally provide optimum copydot reproduction by minimizing contrast gain.

The Mathematical Model

Any continuous function with continuous derivatives can be exactly represented by a Taylor's series or approximated to any desired degree of accuracy by a truncated Taylor's series. If a small enough region is chosen the first three terms of the series are all that are necessary; in other words, the function can be adequately described by a quadratic.

The portion of the (Ah-As) versus lens position curve between the inflection points can be reasonably represented by a quadratic. The noise level in the data is high enough to mask lack of fit, if any, unless considerable replication is employed. Since a quadratic is an approximation only, care must be taken not to interpret this as the correct model or the true form of the relationship. The model will not apply outside the region of data collection.

A logrithmic transofmration of a nonlinear model, such as a gausian, is not appropriate in this case, since we have no reason to suspect that errors are proportional to the magnitude of the response variable.

PROCEDURE

Experimental

Two process cameras were available for use. Using Camera A:

1. A focus series was made in the smallest increment of focus it is felt a cameraman would be likely to use, using an orthochromatic film with white light. Exposure was adjusted by choosing from an exposure series an exposure level giving a pleasing overall density and approximately equal loss of the smallest and largest dots in the halftone step tablet near optimum focus.

2. A green filter (Wratten 61) was placed in front of the lens and a second focus series made. Exposure was adjusted by choosing from an exposure series an exposure level giving approximately the same size highlight dot as previously (about 98%) in a particular step of the halftone step tablet near optimum focus. To check processing variability, replicates of three focus positions were made and processed after the other films.

3. The above procedure was repeated with a blue filter (Wratten 47B).

4. The above procedure was repeated with a blue sensitive contact film and no filter.

5. The above procedure was repeated with a blue sensitive contact film and a uv absorbing filter (Wratten 2C) on a different day.

Using Camera B and a different processor:

1. A focus series was made using the orthochromatic film with no filter. The exposure was adjusted by choosing from an exposure series an exposure level giving approximately the same size highlight dot (about 98%) in the same step of the halftone step tablet as previously. As before, three replicates were made to check processing variability.

2. The above procedure was repeated with a green filter.

3. The above procedure was repeated with a blue sensitive contact film and no filter.

4. The above procedure was repeated with the orthochromatic film and a blue filter on a different day.

Exposure Control

At a later date the validity of the exposure control technique was questioned and investigated. Due to the circumstances, it was necessary to use a third camera. The orthochromatic film was used with no filter. The camera was focused at its optimum, and an exposure series made covering a wide range from very underexposed to heavily overexposed.

Data Analysis

Dot areas were read from the negatives and tabulated using a Kodak densitometer Model 31A. Plots of (Ah-As) versus lens position were made showing the data points, the least squares fit, and the 90% confidence intervals around the data points, for each focus series. A program was written to make it possible to do this on an IBM 1130 with plotter.

The lateral displacement of the optima of two curves is a measure of difference in optimum lens position.

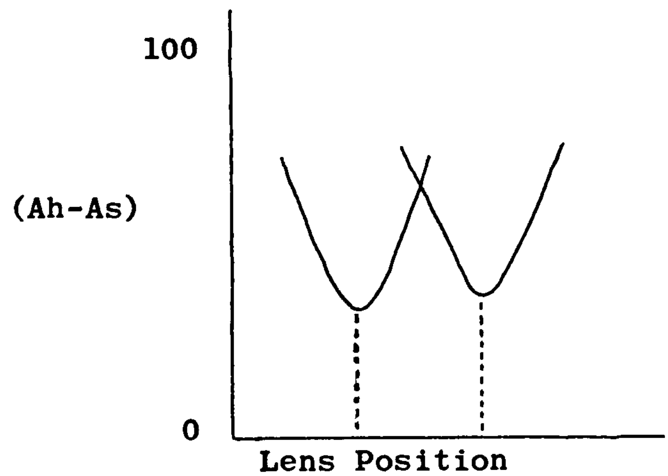


Fig. 4. Difference in Optimum Lens Position

The statistical test of difference in optimum lens position is performed in the following manner. Consider only half of the parabola at a time, as in Figure 5.

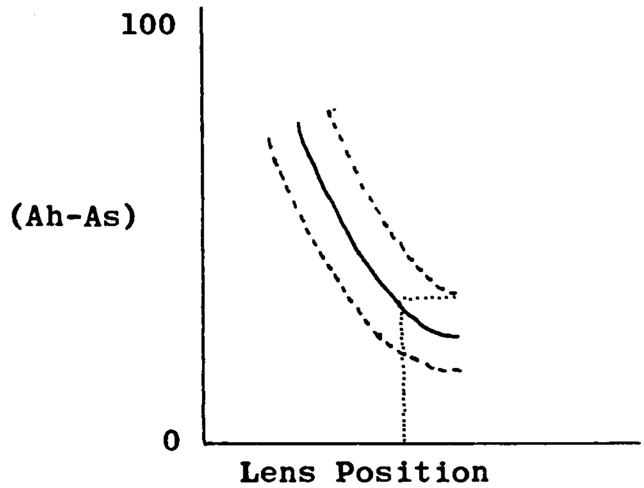


Fig. 5. Confidence Interval Around the X-Value of the Optimum

From the regression analysis we know that point A is the minimum, whose y-value falls, with 90% confidence, between B and C. Any other point whose y-value falls between B and C is not significantly different from A. On the other hand, any point whose y-value is not between B and C--i.e., whose y-value is greater than B--has a y-value significantly different from that of point A. Thus, all points on the curve to the left of point D have y-values different that that of point A at 90% confidence. Since these points are associated with different y-values than point A, and the function is not double-valued, then the points must be associated with different x-values than point A also. A similar analysis is applicable to the other half of the parabola, yielding a confidence interval about the x-value of the minimum. Since any point outside this interval is different from A, any two parabolas whose minima each fall outside the interval around the x-value of the other show significantly different optimum lens positions, provided that the variances in the x-direction are not significantly different, as determined by an F-test.

The horizontal displacement of the optima of two curves is a measure of difference in copydot quality.

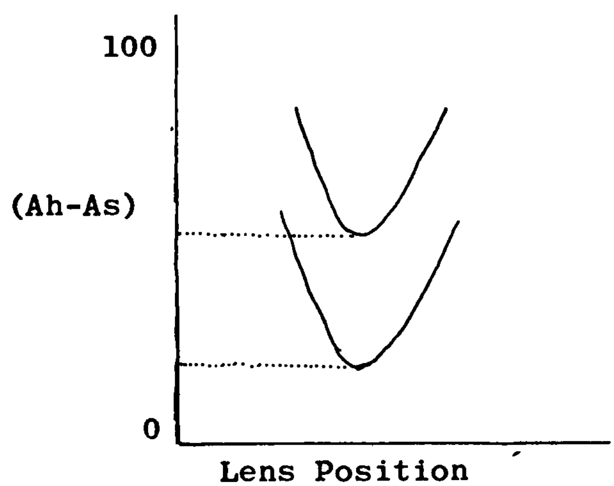


Fig. 6. Difference in Copydot Quality

This statistical test is a bit more straightforward: two curves, each of whose minima have y-values outside the confidence interval around the y-value of the minimum of the other, have significantly different copydot quality. Again it is necessary for the variances (this time in the y-direction) to be close to equal.

The slope of the curve on either side of the minimum is a measure of the effect of defocus on copydot quality.

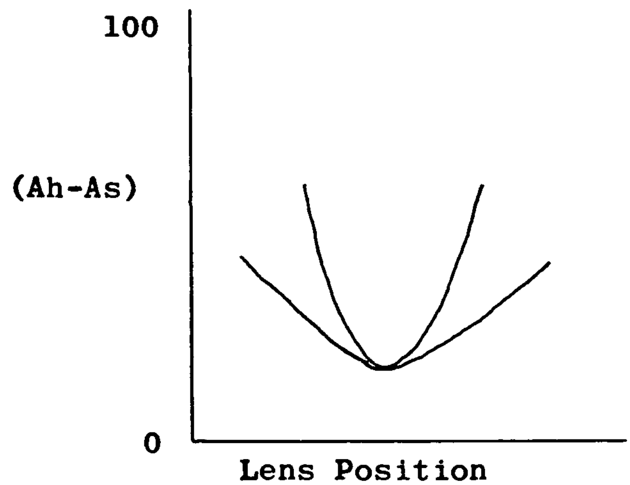


Fig. 7. Difference in the Effect of Defocus

If the minima of two curves are superimposed, and the slope of one is enough different from the other so that at some distance from the minima (within the range of data collection) the y-value of each curve falls outside the confidence interval around the y-value of the other, the curves show a difference in the effect of defocus. The variances in the y-direction, of course, must not be significantly different.

When the variances are different, these tests can still be made, but at an α-risk that is approximately the product of the separate α-risks; in this case, about .01. To accomplish this, the phrase "each falls outside the confidence interval around the other" is replaced with "the confidence intervals do not overlap."

Exposure Control

Since the exposure control method used was to hold highlight dot area at the optimum focus of each series as constant as possible, a plot was made from the exposure series of (Ah-As) as a function of Ah. This relationship is shown in Figure 8. It is seen that as long as one operates on the "uphill" side of the curve the maximum slope is unity. Thus since the maximum deviation of Ah from the aim was ±1%, the maximum deviation of (Ah-As) due to exposure variations is ±1% also; or ±1 scale division on the plots.

Another exposure control method was suggested by Dr. G. W. Schumann. In this method a plot is made of (Ah-As) as a function of (Ah+As). This relationship is shown in Figure 9.

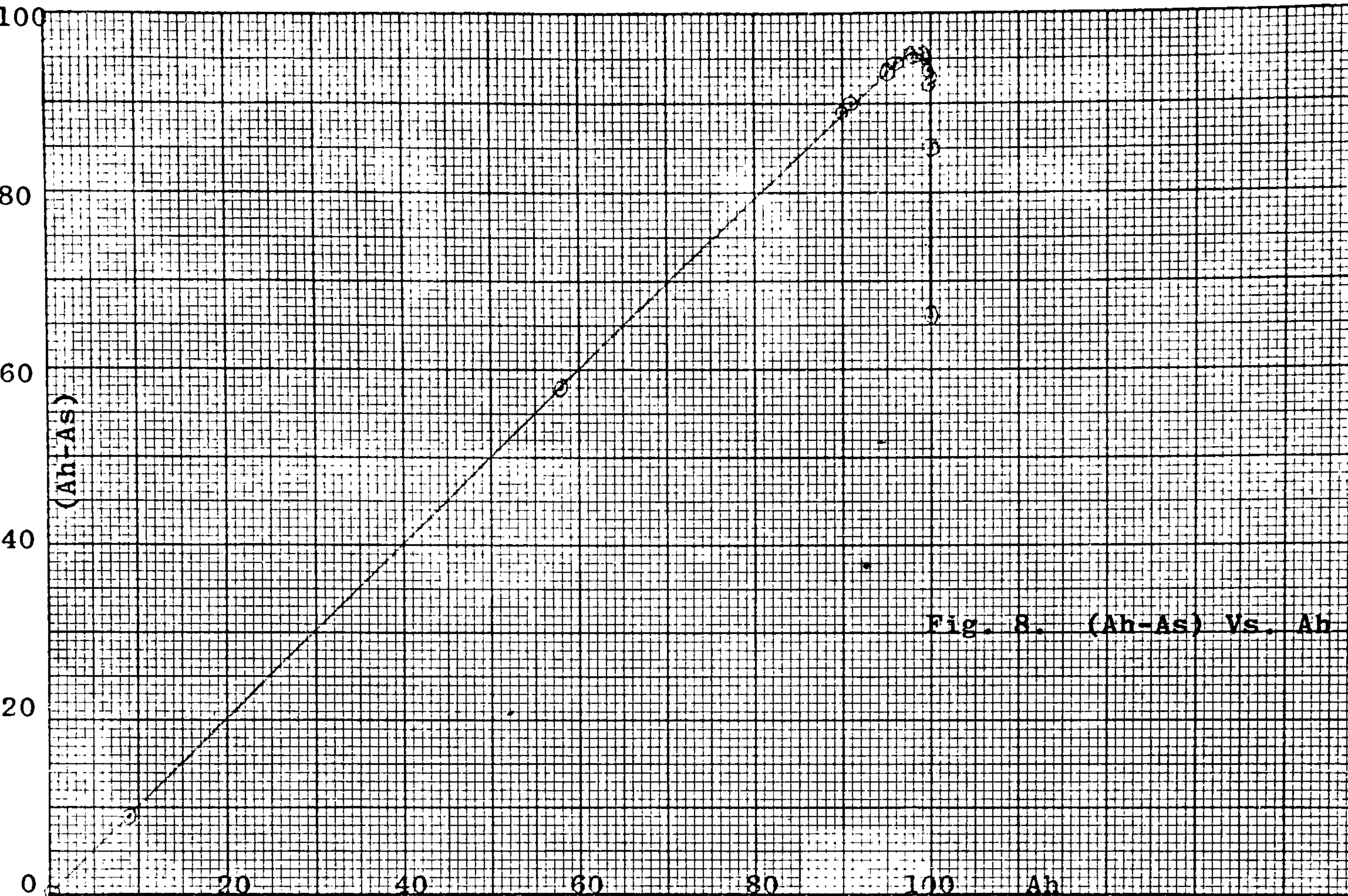


Fig. 8. (Ah-As) Vs. Ah

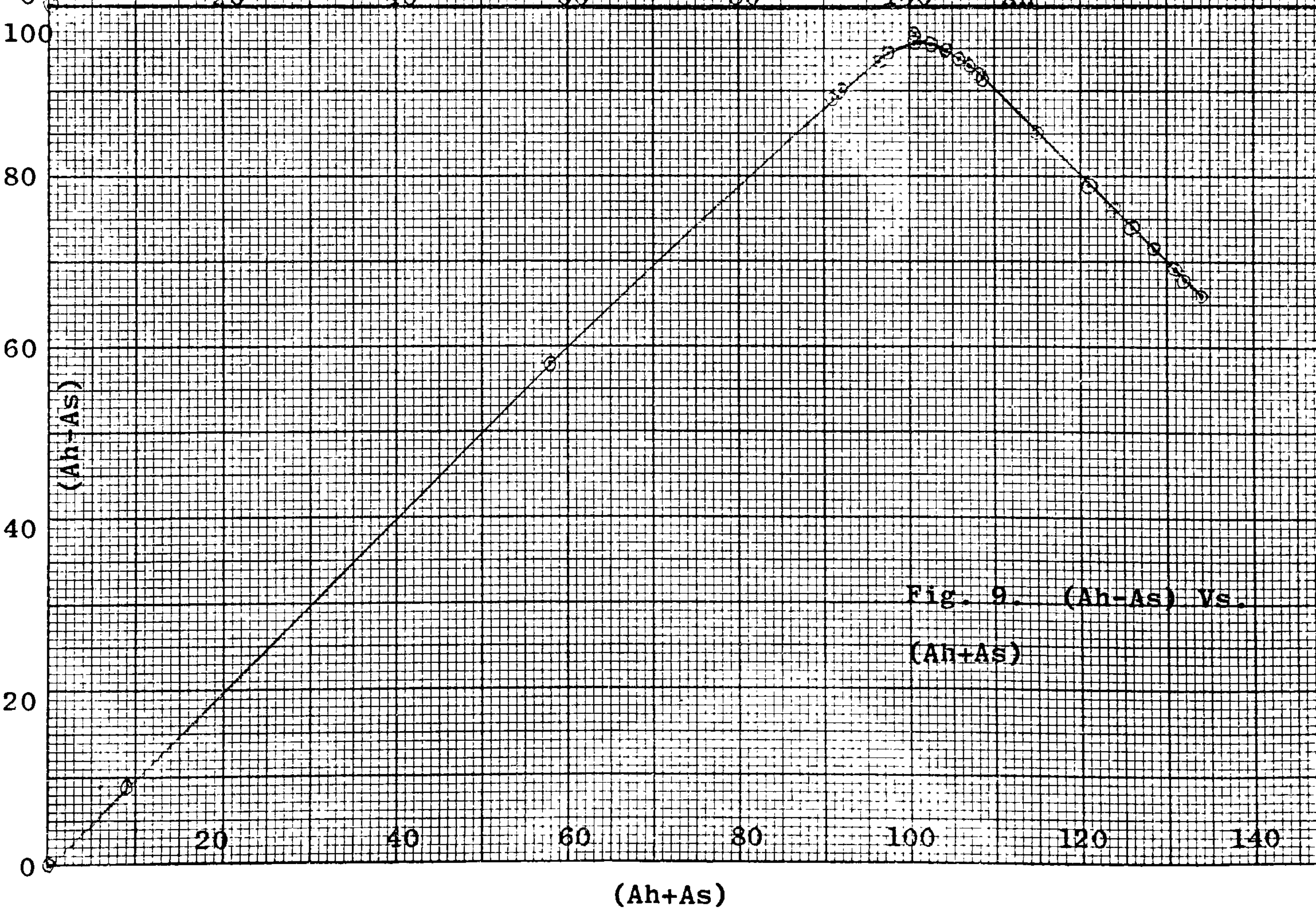


Fig. 9. (Ah-As) Vs. (Ah+As)

If (Ah+As) is held constant near the center of the plot where $\frac{d(Ah-As)}{d(Ah+As)} = 0$, then small variations in (Ah+As) with exposure level will affect (Ah-As) relatively little.

Unfortunately, to be sure of working in the center region of the curve, one must make an exposure series at each condition, since both the abscissa and ordinate values of the center are likely to change with the sizes of the original dots, the optics, copydot quality of the film, and the processing. When working away from the center, the maximum slope is again unity, and the exposure control would be as good as the previous method.

RESULTS

On the following pages are the plots generated. The three lines in each case are the upper confidence limit (X), the fitted line (+), and the lower confidence limit (▷). The points (+) with no lines passing through are the individual data points. The smallest division of the abscissa is .005 of the focal length of the lens.

The photomicrographs in Figure 19 confirm that these plots do, indeed, predict the best focus.

The summary plots in Figures 20 and 21 show the confidence intervals around the optima of the various curves, allowing the reader to quickly verify any conclusion.

It was found from the exposure series that the small differences in exposure level between conditions could not produce an error in (Ah-As) greater than ±1 scale division. This did not change the results of any of the tests.

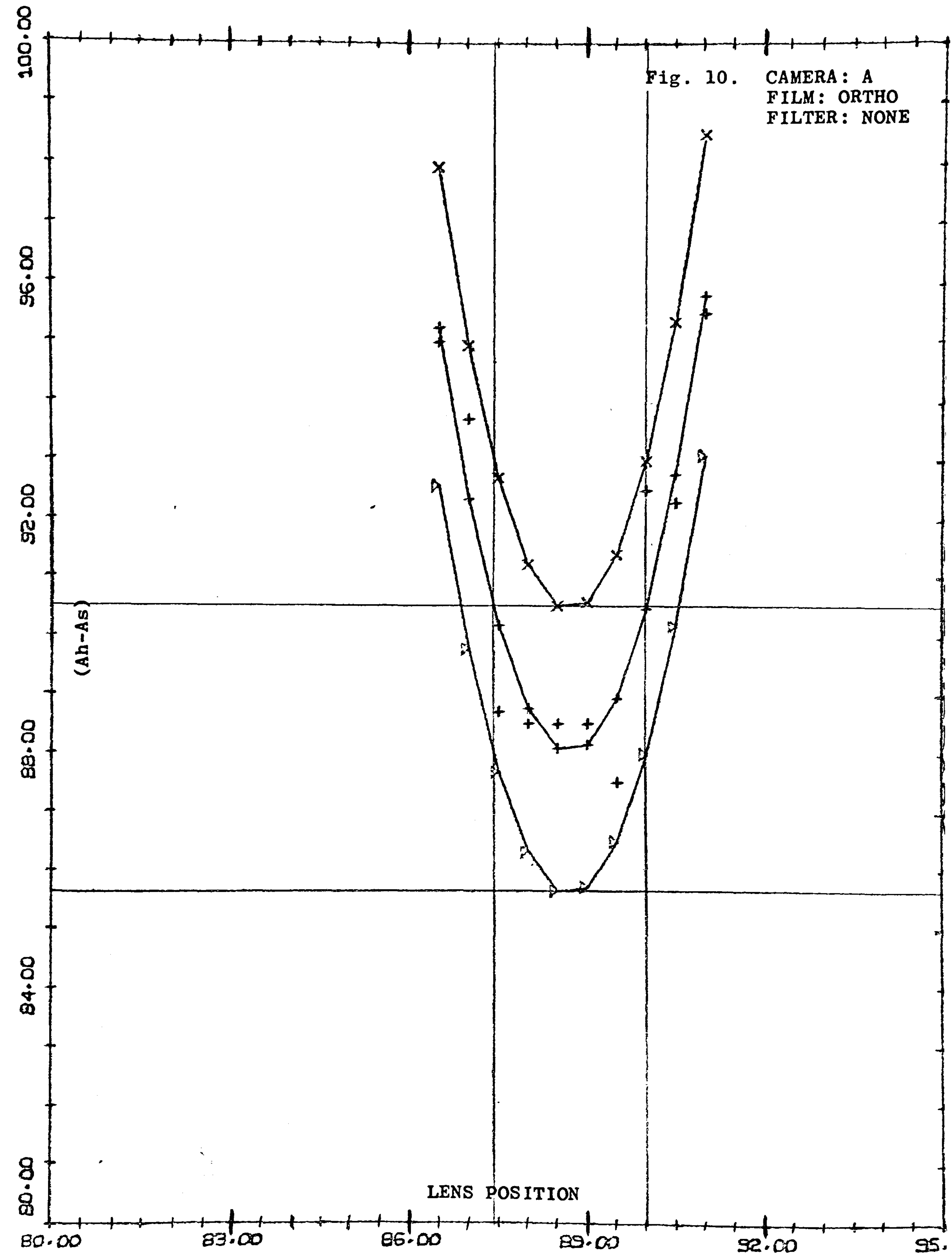


Fig. 10. CAMERA: A
FILM: ORTHO
FILTER: NONE
100.00
96.00
92.00
88.00
84.00
80.00
(Ah-As)
LENS POSITION
80.00
83.00
86.00
89.00
92.00
95.

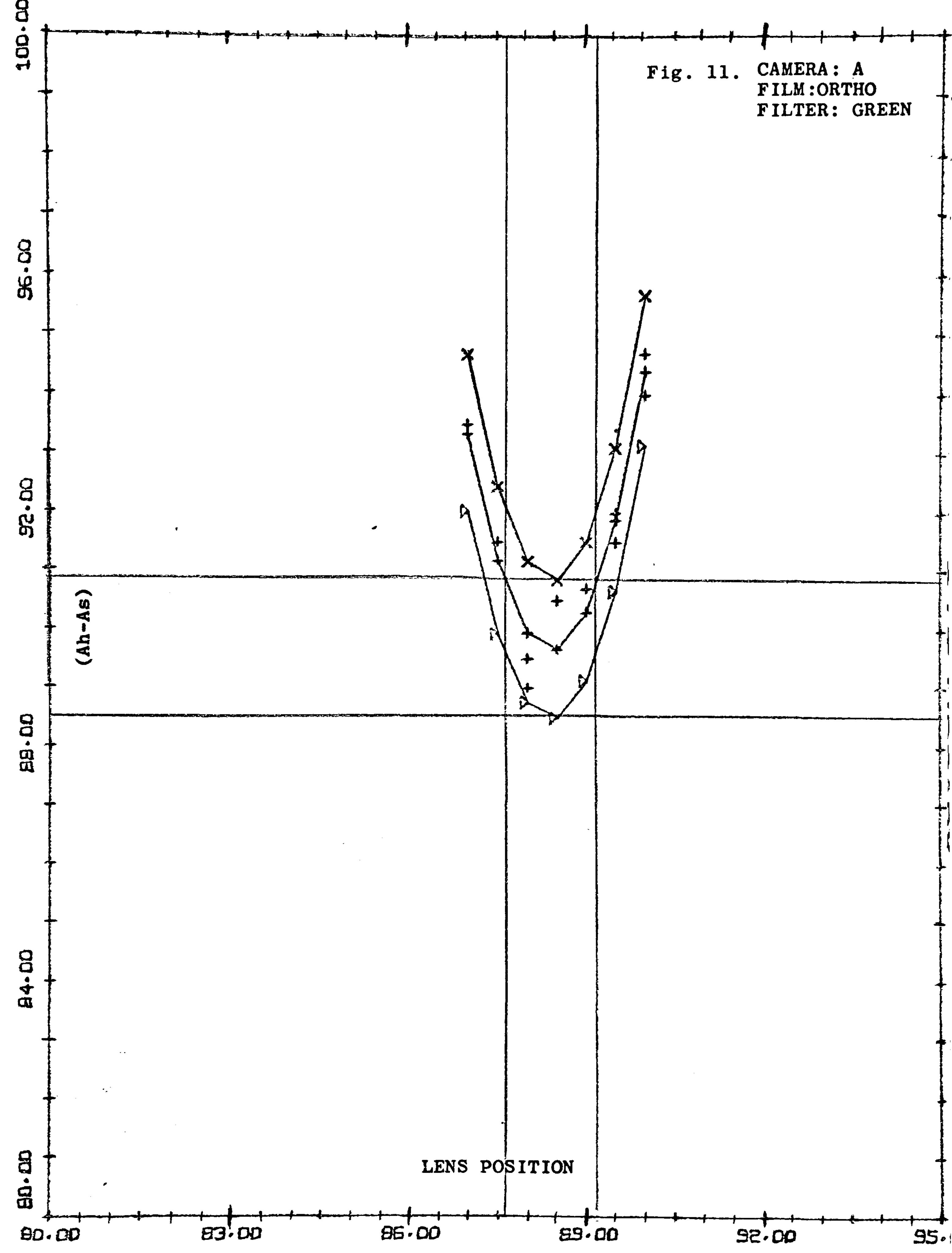


Fig. 11. CAMERA: A
FILM:ORTHO
FILTER: GREEN

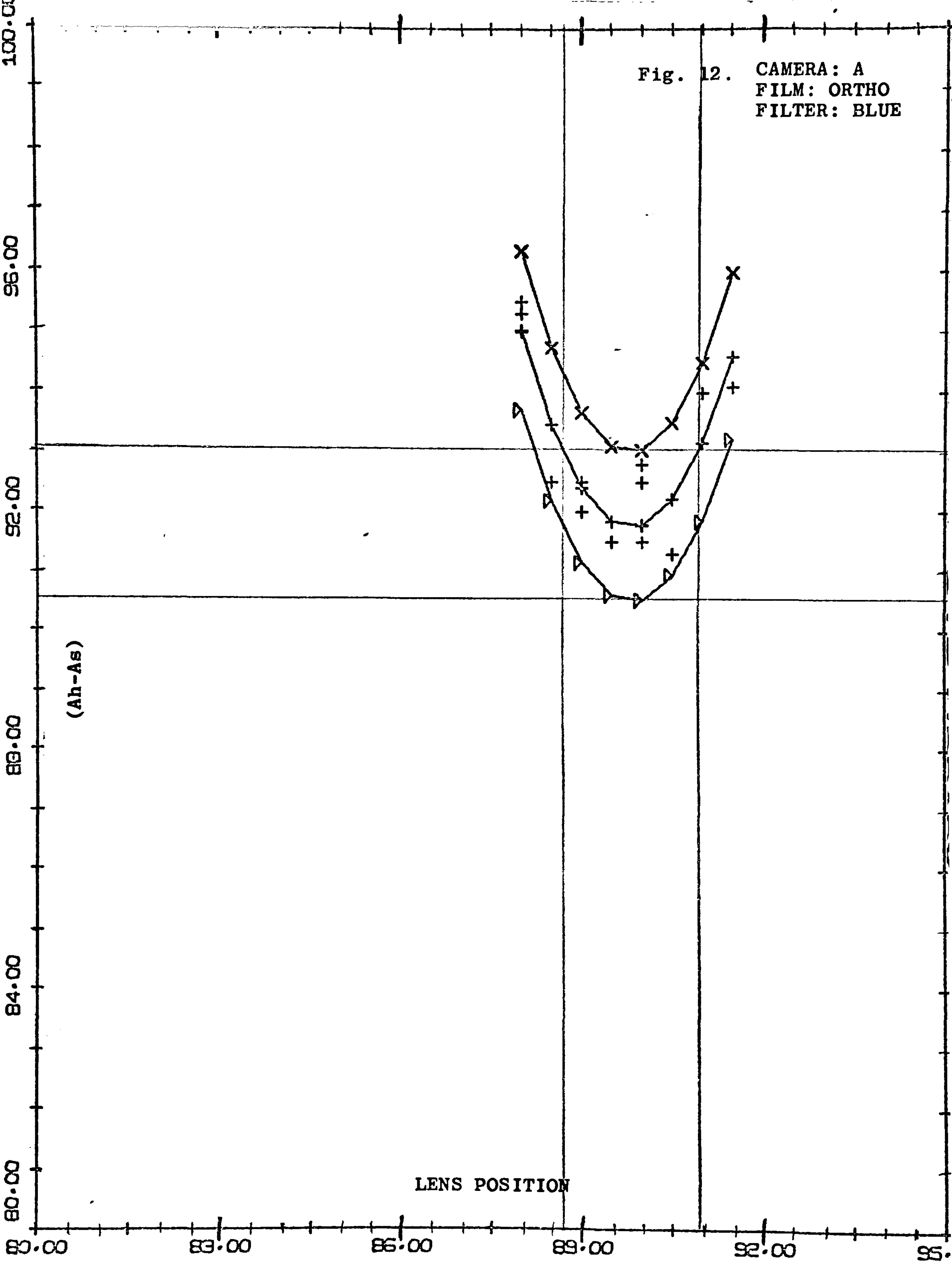

CAMERA: A
FILM: ORTHO
FILTER: BLUE
(Ah-As)
LENS POSITION
80.00
84.00
88.00
92.00
96.00
80.00
83.00
86.00
89.00
92.00

Fig. 12.

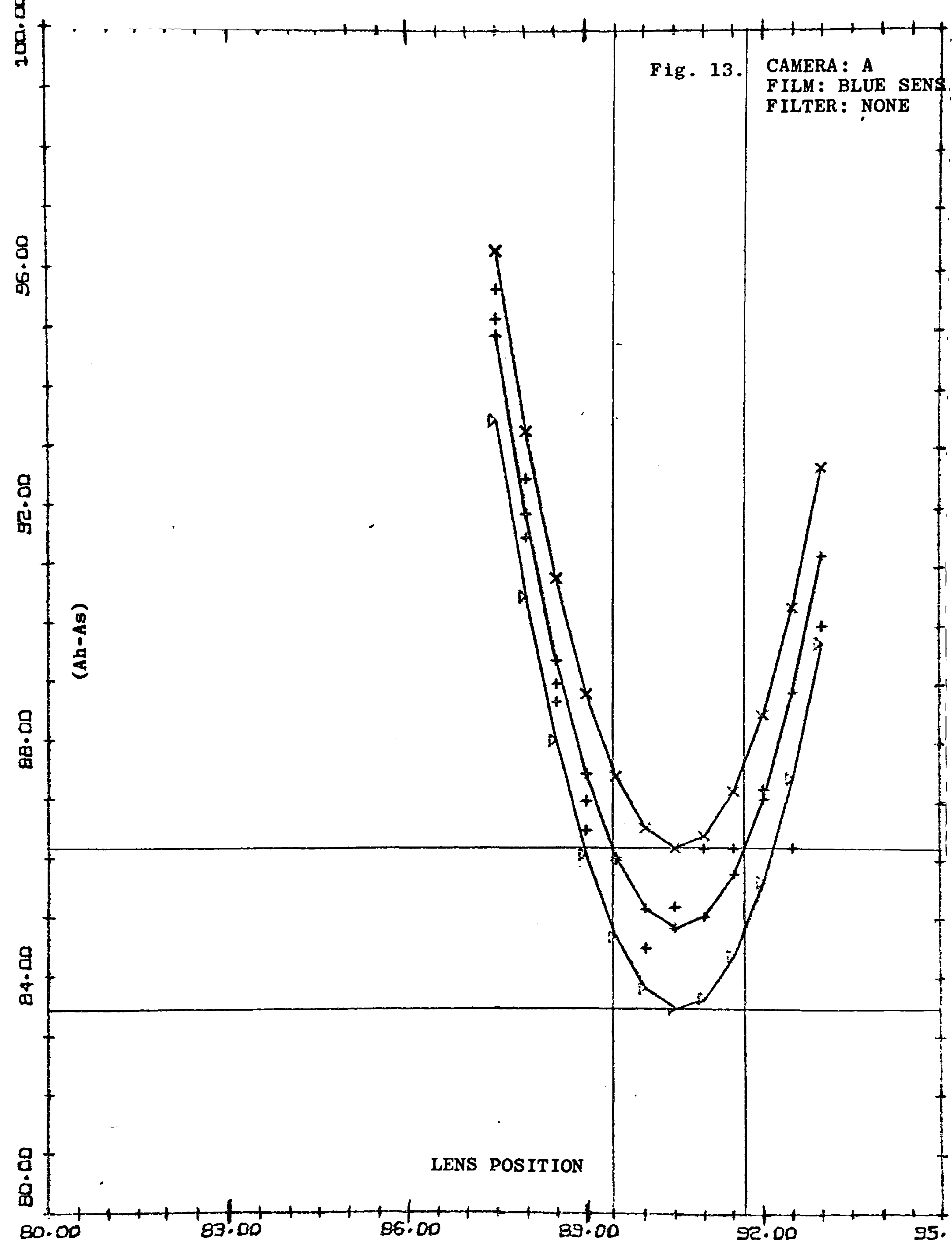


Fig. 13.
CAMERA: A
FILM: BLUE SENS.
FILTER: NONE
(Ah-As)
LENS POSITION
100.00
96.00
92.00
88.00
84.00
80.00
80.00
83.00
86.00
89.00
92.00
95.

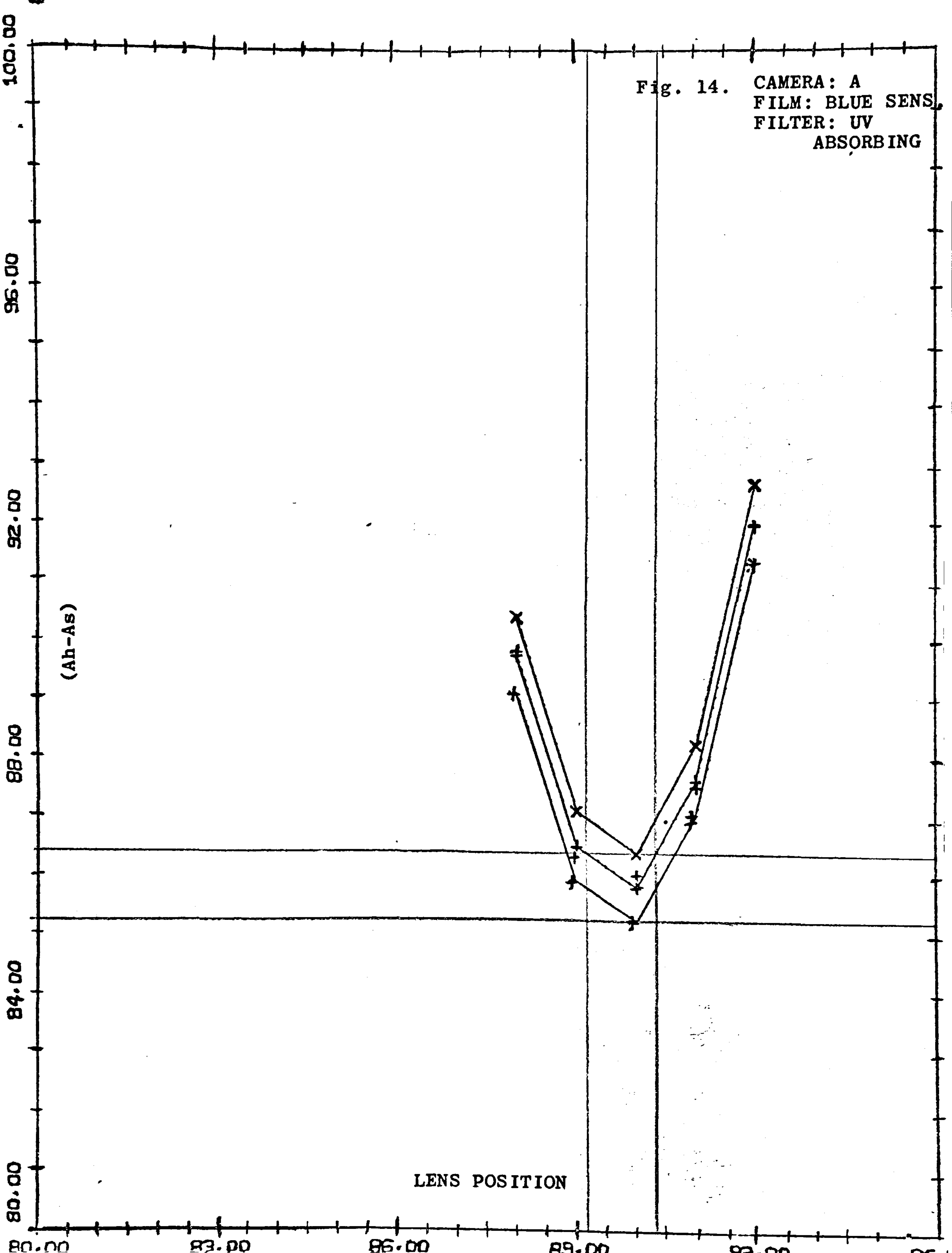

CAMERA: A
FILM: BLUE SENS,
FILTER: UV
ABSORBING
(Ah-As)
LENS POSITION
100.00
96.00
92.00
88.00
84.00
80.00
80.00
83.00
86.00
89.00
92.00

Fig. 14.

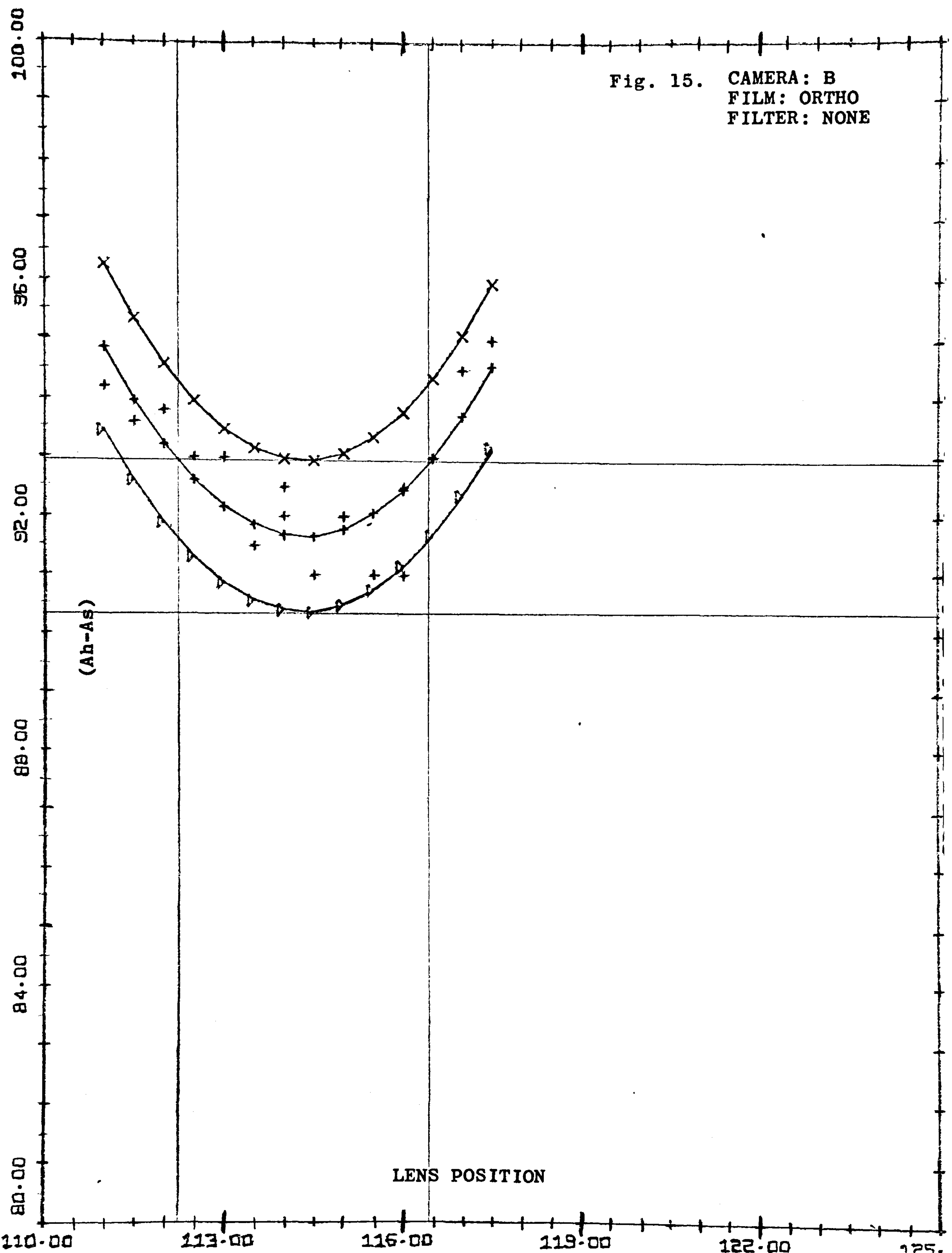


Fig. 15. CAMERA: B
FILM: ORTHO
FILTER: NONE
(Ah-As)
LENS POSITION
100.00
96.00
92.00
88.00
84.00
80.00
110.00
113.00
116.00
119.00
122.00

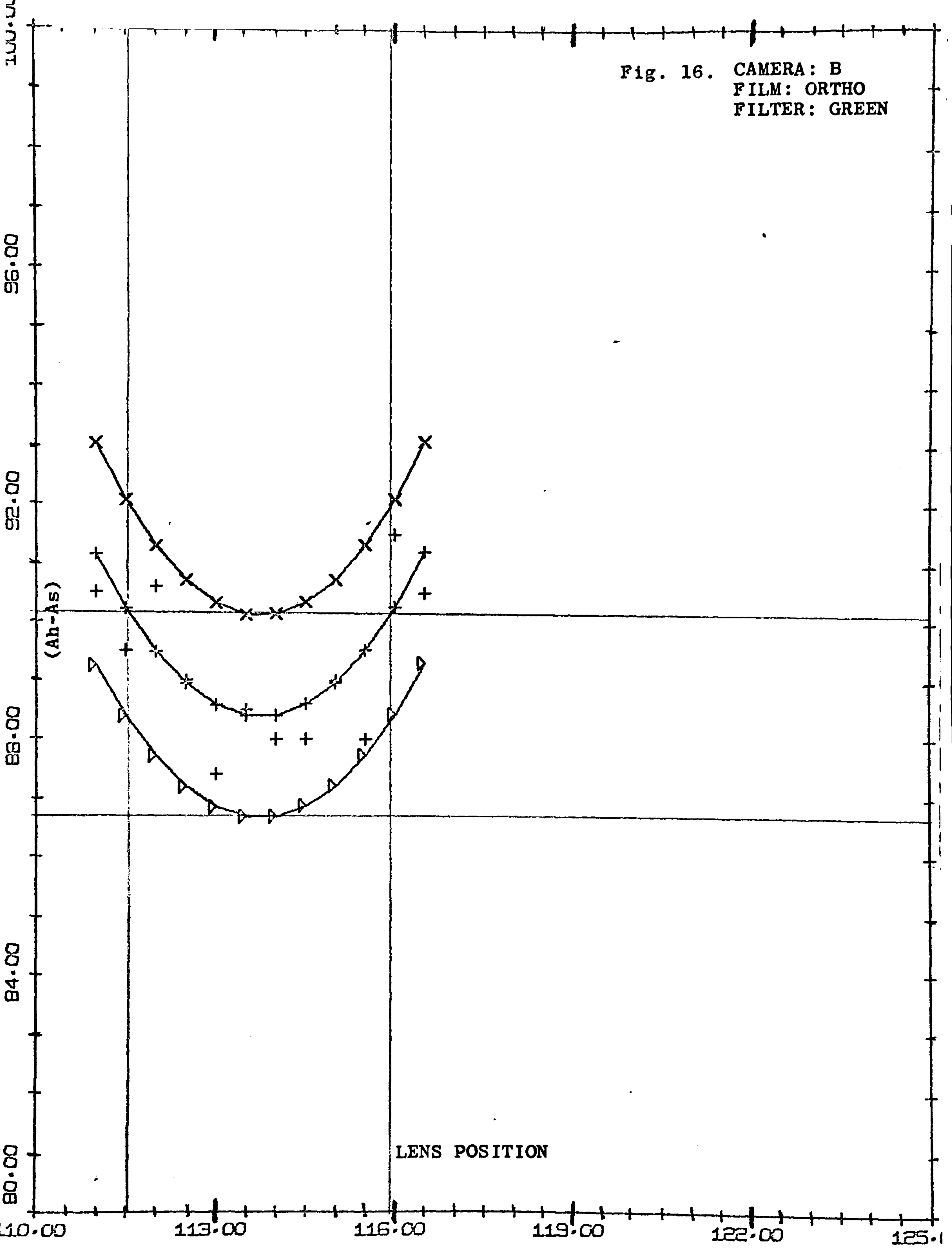


Fig. 16. CAMERA: B
FILM: ORTHO
FILTER: GREEN
(Ah-As)
LENS POSITION
80.00
84.00
88.00
92.00
96.00
110.00
113.00
116.00
119.00
122.00

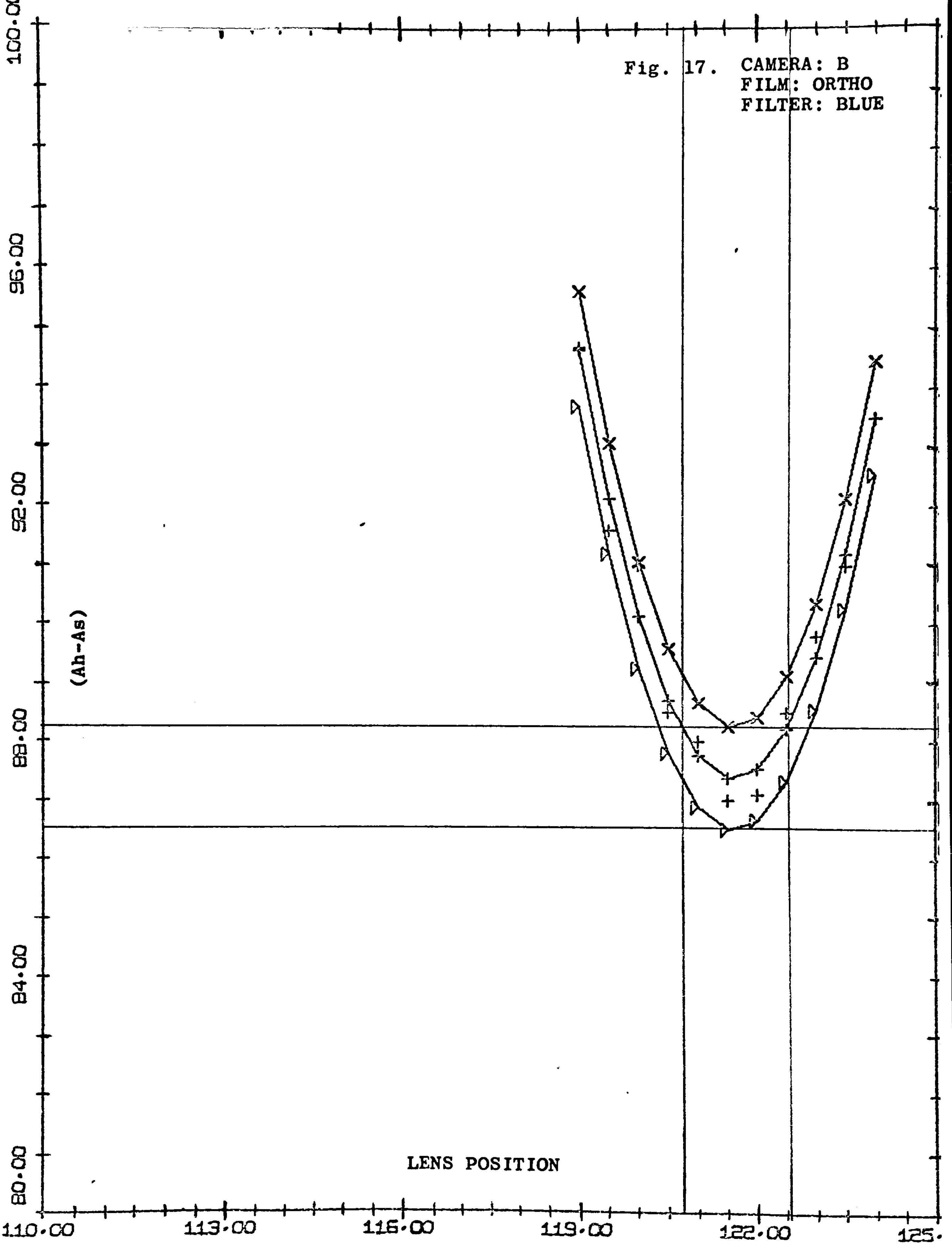


Fig. 17.
CAMERA: B
FILM: ORTHO
FILTER: BLUE
(Ah-As)
LENS POSITION
100.00
96.00
92.00
88.00
84.00
80.00
110.00
113.00
116.00
119.00
122.00
125.

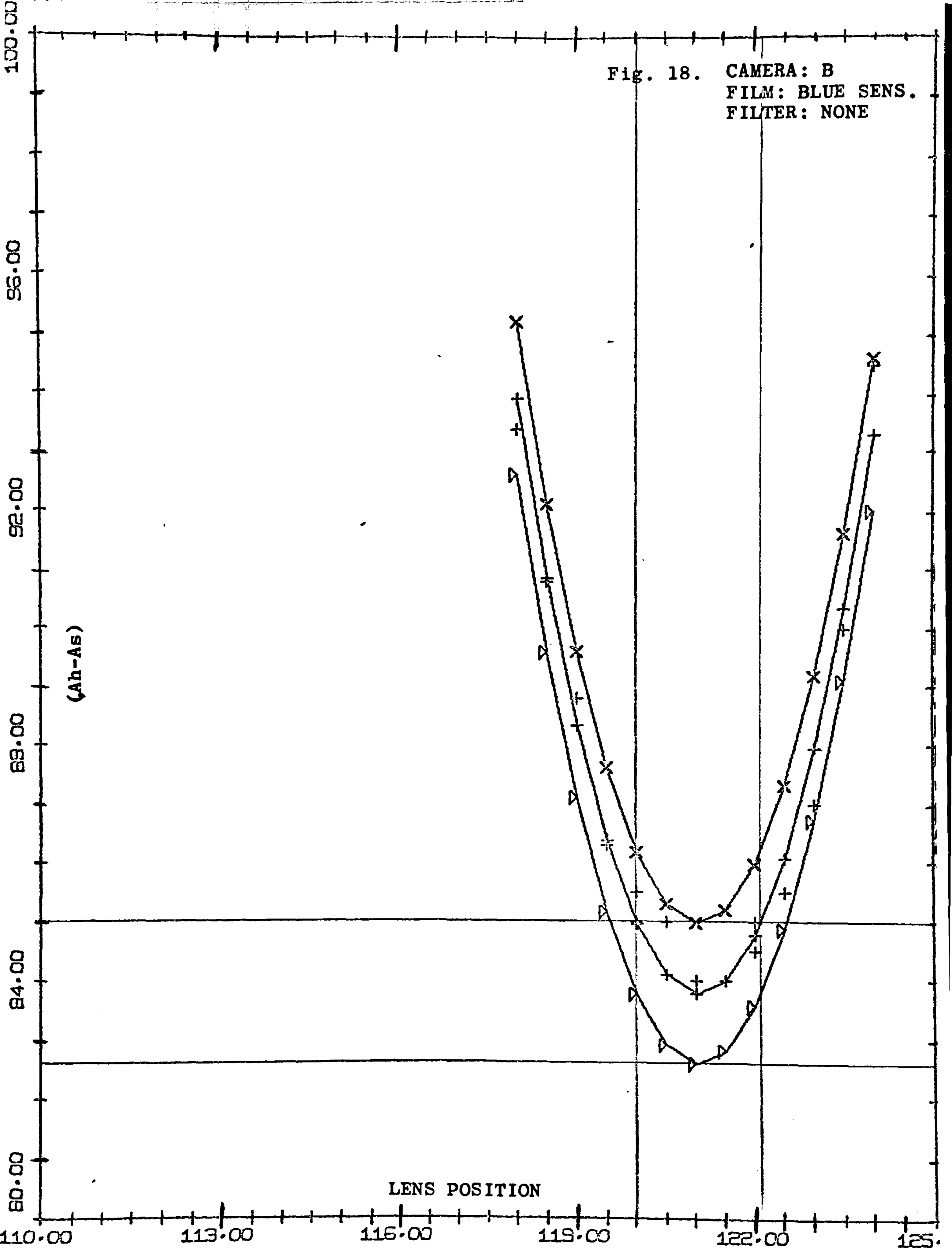


Fig. 18.
CAMERA: B
FILM: BLUE SENS.
FILTER: NONE
(Ah-As)
LENS POSITION
100.00
96.00
92.00
88.00
84.00
80.00
110.00
113.00
116.00
119.00
122.00
125.

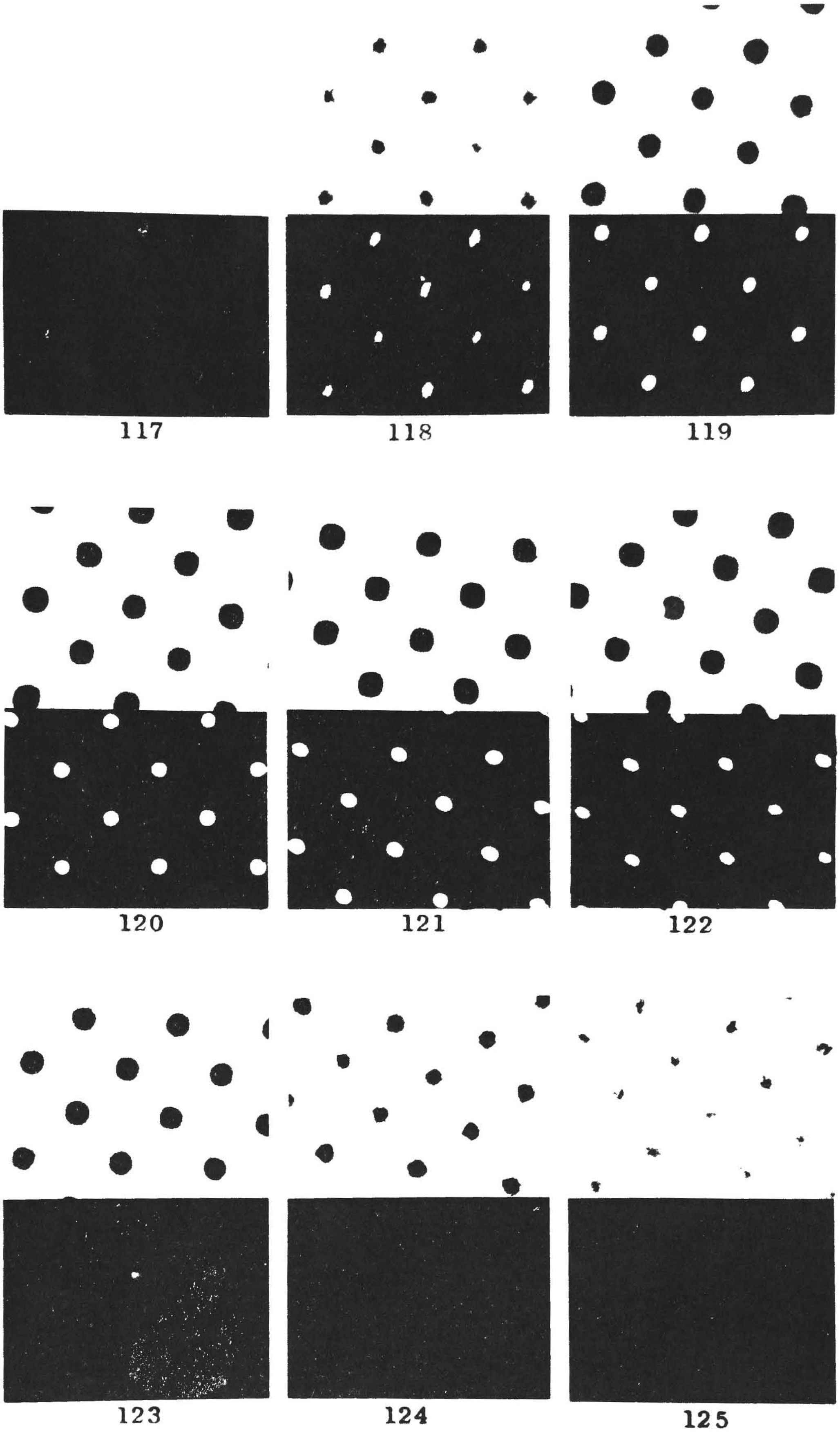


Fig. 19. Photomicrographs of the measured dots. These dots were selected from the focus series made with camera B on the blue sensitive contact film, to confirm that best focus is indeed predicted by the parabola. The number under each set indicates the lens position at which the negative was made.

Fig. 20

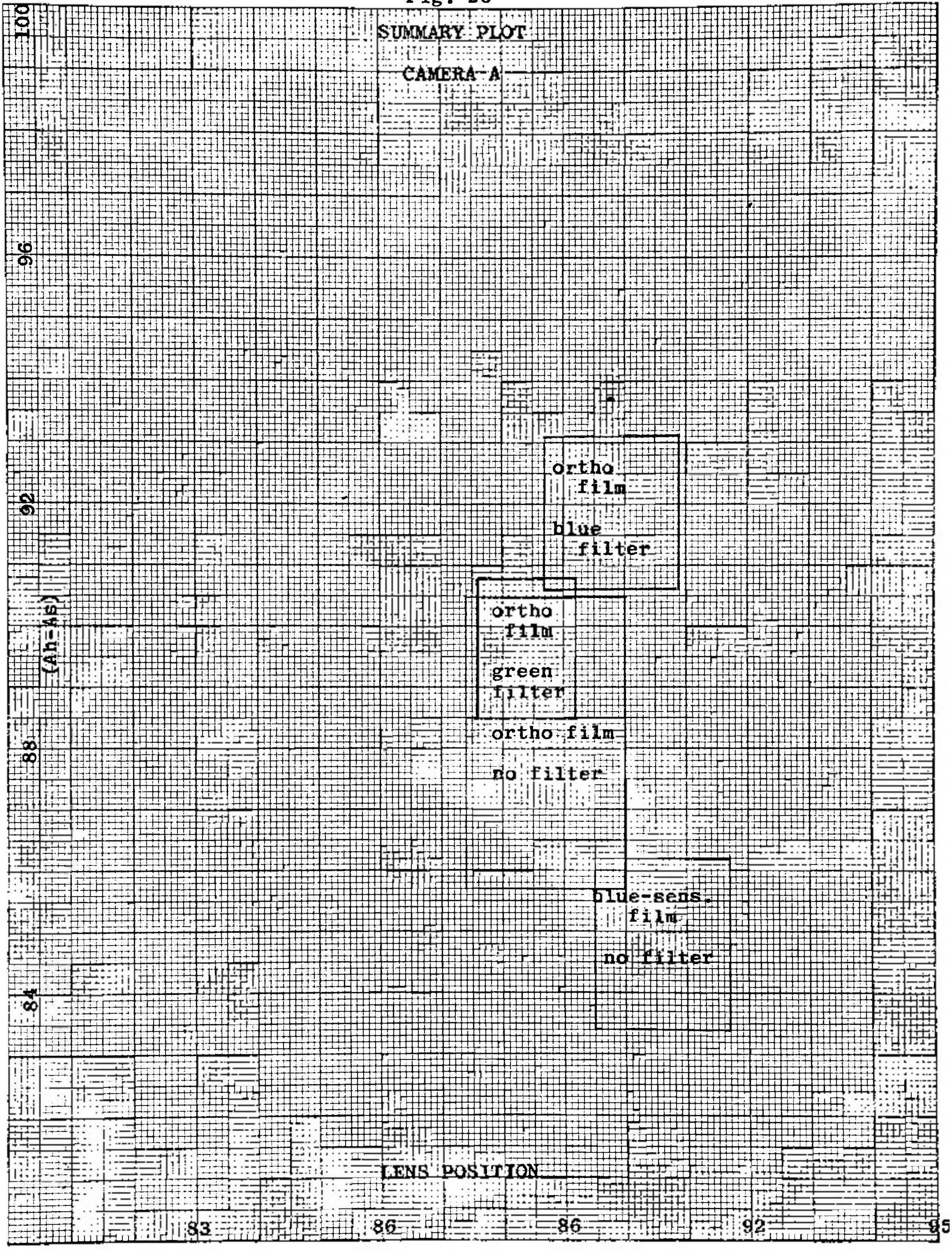
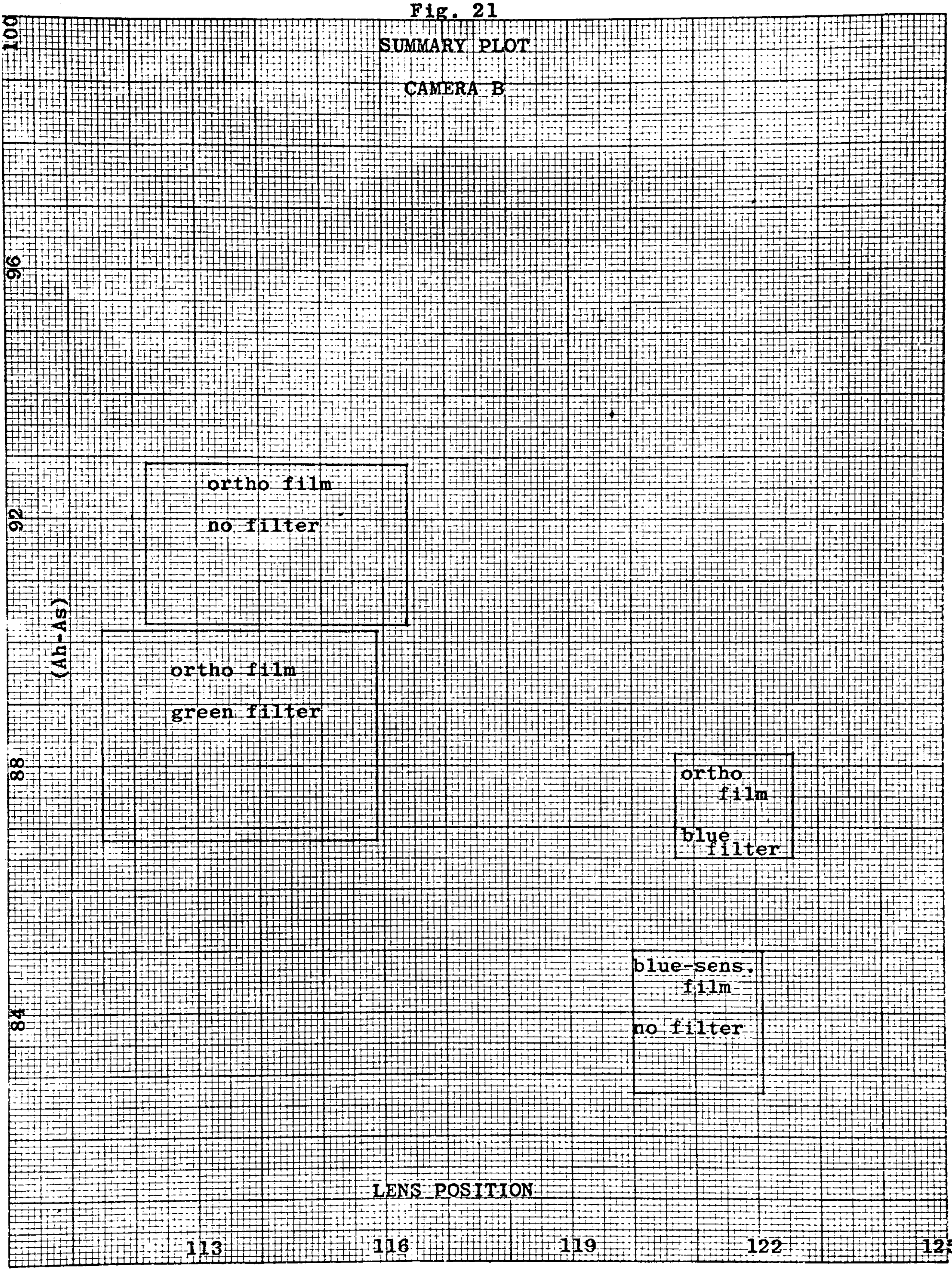

SUMMARY PLOT
CAMERA-A
100
96
92
(Ah-As)
88
84
ortho film
blue filter
ortho film
green filter
ortho film
no filter
blue-sens. film
no filter
LENS POSITION
83
86
86
92
95

Fig. 21


SUMMARY PLOT
CAMERA B
100
96
92
88
84
(Ah-As)
ortho film
no filter
ortho film
green filter
ortho film
blue filter
blue-sens. film
no filter
LENS POSITION
113
116
119
122

CONCLUSIONS AND DISCUSSION

Lens Position

The order of optimum lens positions is given below. Lines are drawn between positions not found significantly different from each other.

camera	A		A		A		A
film	blue sens.	>	ortho	>	ortho	>	ortho
filter	none		blue		none		green

camera	B		B		B		B
film	ortho	>	blue sens.	>	ortho	>	ortho
filter	blue		none		none		green

To state this in words: The blue sensitive film and the ortho film with blue filter focus in about the same place, the ortho film with green filter has a significantly different focus, and the ortho film with no filter focuses in between.

Wherever there is a significant difference in optimum focus, any test of the relative copydot quality of two conditions that does not include a focus series is questionable. Take Camera B for an example. Superimposing the plots shows that the optimum foci of the two different films,(both without filters) differ by about 6 1/2 divisions of the focusing tape ($\cong$ .06f)! The two films are also widely different in copydot quality. The unwary eameraman comparing these films will decide that the orthochromatic film is better for copying dots if his lens is closer to the film plane than 118. This is fairly likely if he focused with white light on the ground glass. He will draw the correct conclusion--that the blue sensitive film is best for copydot--if his lens is farther from the film plane than 118. A similar but less pronounced situation is observed by superimposing the plots made with Camera A. It is clear that lens B has by far the larger chromatic difference of focus.

It had been suggested that the differences in lens position observed in preliminary experiments were due to differences in sensitivity to and absorption of radiation in the near ultraviolet (300-400 nm). The focus series made with lens A, blue sensitive film, and uv absorbing filter, showed no significant difference in focus from the series under similar conditions without the filter, demonstrating that the uv was not a significant contributor to the observed differences. UV is not a suspected problem with Camera B, as the tungsten-halogen light source used emits little uv.

Depth of Focus

Observed depths of focus are arranged in order from greatest to least depth below. Lines are drawn between conditions not found significantly different from each other.

camera	B		B		A		B		A		B		A		A
film	ortho	>	ortho	>	ortho	>	blue sens.	=	blue sens.	=	ortho	>	ortho	>	ortho
filter	none		green		blue		none		none		blue		none		green

Superior depth of focus was shown by lens B with the orthochromatic film and no filter, and with a green filter. A plausible explanation of this phenomenon is that the green focus is already so diffuse with this poor quality lens that it takes a large change in position to degrade it significantly. Adding blue flare light (the essential effect of removing the green filter, since the blue image is so far out of focus near the green focus) makes little difference since the blue is such a small portion of the total available actinic radiation.

Copydot Quality

The conditions are ranked from best to worst copydot quality below. Lines are drawn between conditions not found significantly different from each other.

camera	A		A		A		A
film	blue sens.	>	ortho	>	ortho	>	ortho
filter	none		none		green		blue

camera	B		B		B
film	blue sens.	>	ortho	>	ortho
filter	none		green		none

The copydot quality of negatives exposed on different cameras are not comparable, as the two cameras are in different locations and were used at different times, necessitating the use of different processing conditions. Nonetheless, it is clear that the blue sensitive film shows copydot quality superior to the ortho film when the camera is properly focused.

It seems, from the above data, that Camera A focuses white light well enough that the addition of a filter to the system causes as much or more image degradation (through the flare light resultant from the extra interfaces) as the unchecked chromatic aberration. Camera A, on the other hand, benefits significantly from the addition of a filter.