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# Design of an experiment using the Hartmann test to evaluate progressive addition lenses

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# Design of an experiment using the Hartmann test to evaluate progressive addition lenses

**Abstract**

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**Degree Type**

Thesis

# DESIGN OF AN EXPERIMENT
# USING THE HARTMANN TEST
# TO EVALUATE PROGRESSIVE ADDITION LENSES

# DESIGN OF AN EXPERIMENT USING THE HARTMANN TEST TO EVALUATE PROGRESSIVE ADDITION LENSES

by

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A Paper Submitted in Partial Fulfillment
of the Requirements of the Degree of Doctor of Optometry
Pacific University College of Optometry
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# GRADE SHEET AND COMMENTS

Design of an experiment using the Hartmann Test to evaluate progressive addition lenses.

Advisor - Dr. J. Meyer-Arendt

## ACKNOWLEDGEMENTS

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C.M.S.

M.D.B.

# INTRODUCTION

An experiment was designed for use in the Pacific University Optics Laboratory to demonstrate certain properties of progressive addition lenses. The Hartmann Test was chosen to evaluate a flat top 25 bifocal lens, a flat top 25 trifocal lens and two widely used progressive addition lenses, Varilux II by Titmus and Ultravue by American Optical.

The Hartmann test was chosen for several reasons. Historically, it has long been a method of evaluating the lenses and mirrors used in astronomical telescopes, devices where the utmost in optical quality is essential. Second, it is a simple test and can be performed accurately with a minimum of equipment. Lastly, though quantitative evaluation of the resultant dot pattern can be very complicated, relative qualitative judgments are simple. The use of different types and powers of progressive addition lenses causes variations in the Hartmann dot pattern that are immediately obvious to even a casual observer and clearly show the unique optical properties of each lens under test.

The Hartmann test (essentially a method of empirical ray tracing) in its simplest form consists of using an opaque mask filled with a series of perforations which allow pensils of light to pass through the mask and strike selected portions of the lens under test. It is an extension of the method used by Prechtl (1828) in demonstrating spherical aberrations.[1] The intersection of these rays with a common plane, as recorded on photographic film set away from the Gaussian focus of the rays, may then be used to determine the amount of the spherical aberration and coma existing in a given lens or mirror. This is possible since, in essence, a three-dimensional picture of ray paths can be generated from the photographs and compared to theoretical ray paths to show deviation from the ideal.[1] Assuming that each ray contains the same amount of light energy, the density of the points in the image plane can also be a measure of the intensity distribution if diffraction is neglected.[2]

In recent years there have been several improvements to the Hartmann test.[3,4,5,6,7] In this regard, one modification reported by Schulte[4] for improved testing of astronomical mirrors involves placing limitations on the size and placement of apertures in the mask. Schulte's modification allowed the fabrication of a computer generated, easily readable, topographical map of the mirror surface. Another improvement reported by Shack and Platt[7] involved replacement of the conventional perforated screen by an array of contiguous lenticular elements, each 1 millimeter square and having a focal length of 125 millimeters. The photographic recordings were then made in the common focal plane of these lenticular elements. The advantages of this modification were a conveniently sized test instrument, complete contiguous sampling of the test lens aperture, and small-sized recorded spots with relatively large separations.

The experimental Hartmann test that we have used involves only the original perforated mask. The principles of ray tracing could still be demonstrated in this way, without the complications involved in using computers or creating specialized masks.

## DESCRIPTION OF APPARATUS

The apparatus used in this experiment was constructed as shown in figure 1.

List of Components:

1) A 6 volt sealed beam spot light
2) Aluminum disc with 1 mm diameter pinhole
3) Black Cardboard Tube of 18 cm diameter
4) Hartmann Screen (grid of 1.07 mm diameter holes spaced 2.54 mm apart)
5) Lens holders (2)
6) Test lenses
7) Focusing Lens - 10 mm diameter, power +4.75 D
8) Viewing Screen or Photographic film
9) Frosted Glass

Dimensions of Apparatus: (see figure 2)

| | |
|---|---|
| Pinhole to grid | 109.30 cm |
| Grid to center of focusing lens | 1.30 cm |
| Center of focusing lens to film plane | 11.35 cm |
| Test lens to film plane | 10.30 cm |

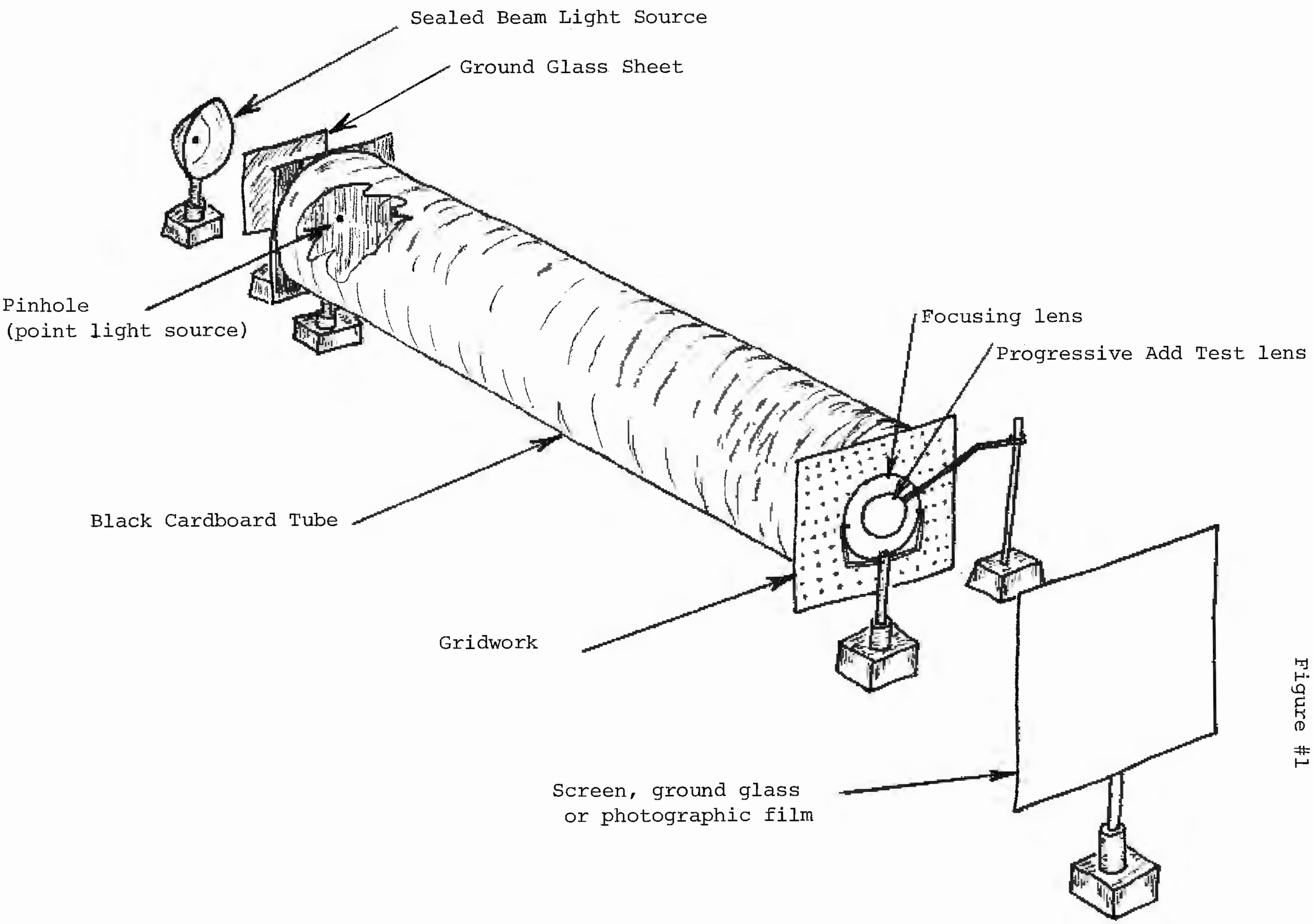
Sealed Beam Light Source
Ground Glass Sheet
Pinhole
(point light source)
Focusing lens
Progressive Add Test lens
Black Cardboard Tube
Gridwork
Screen, ground glass
or photographic film

Figure #1

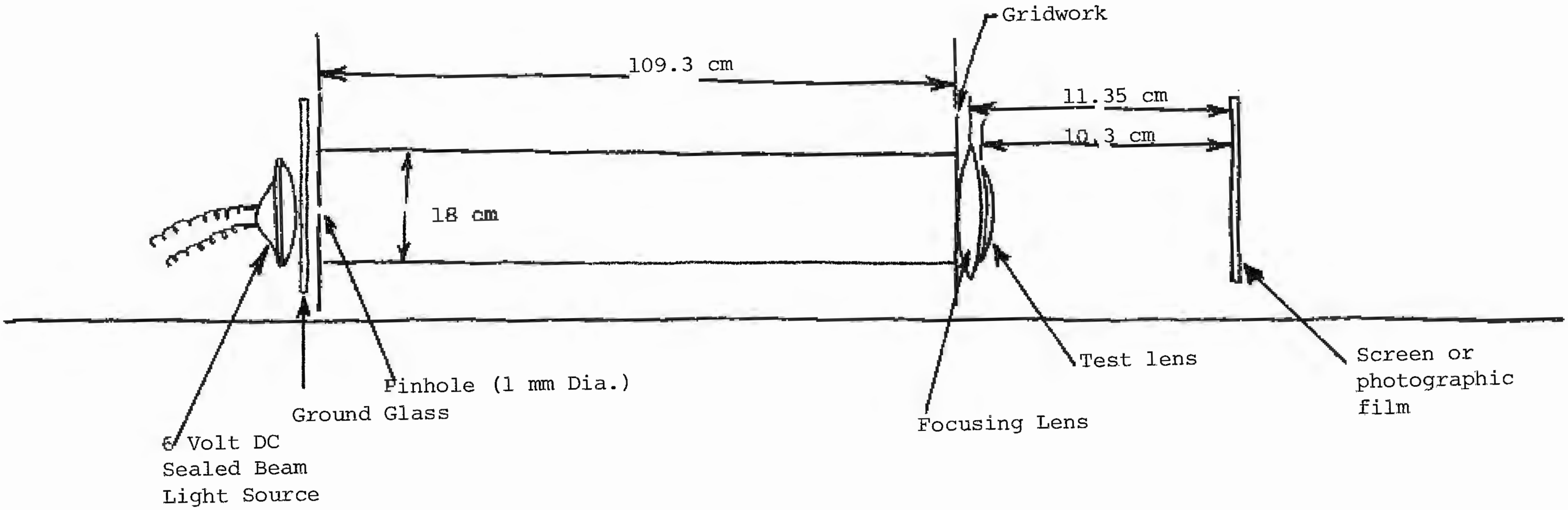
Gridwork
109.3 cm
11.35 cm
10.3 cm
18 cm
Test lens
Screen or
photographic
film
Pinhole (1 mm Dia.)
Ground Glass
Focusing Lens
6 Volt DC
Sealed Beam
Light Source

Figure #2

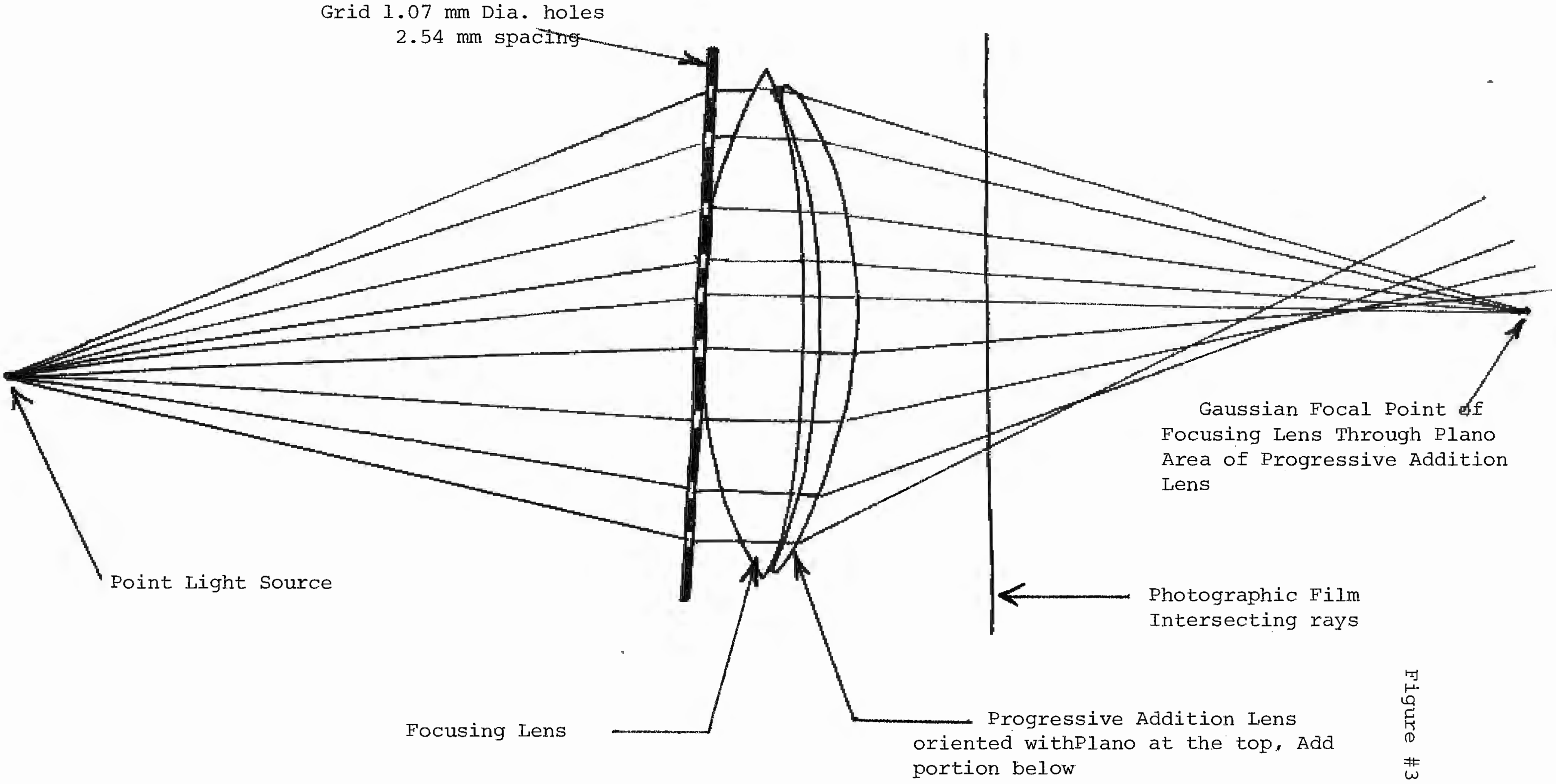
Grid 1.07 mm Dia. holes
2.54 mm spacing
Gaussian Focal Point of
Focusing Lens Through Plano
Area of Progressive Addition
Lens
Point Light Source
Photographic Film
Intersecting rays
Focusing Lens
Progressive Addition Lens
oriented withPlano at the top, Add
portion below

Figure #3

## PROCEDURE

The components of the apparatus are arranged as shown in figures 1 and 2.

Stray light from the light source can interfere with viewing or photography of the Hartmann pattern and should be eliminated by baffles or other appropriately placed opaque shielding. Seal the tube where it contacts the pinhole plate and the Hartmann grid so that no stray light enters the tube itself. The object is to have only light from the pinhole falling upon the grid.

The test lens is inserted into the lens holder and placed in contact with the focusing lens which has previously been securely mounted in contact with the grid.

For direct viewing of the resultant Hartmann pattern, place a white screen or ground glass at various distances from the test lens and observe the changes in the pattern.

If photographs of the pattern are to be taken, choose a location for the film plane that gives the desired resolution. Best exposures for this particular apparatus were in the range of 30-45 seconds using Kodak Kodalith 4" x 5" sheet film, ASA 6. Developing time in Kodalith developer was 7 minutes.

## DISCUSSION

The ray diagram shown in figure 3 illustrates how the patterns on the photographs were produced.

Each photograph represents the cross sectional pattern of the rays emerging from the test lens at a point offset from the actual

Gaussian focal point. (If the cross-section were to intersect the rays at or very near the Gaussian focus the rays would blend together into a single spot and information concerning the rays would be lost.) By placing the cross-sectional plane between the focusing lens and the Gaussian focus of the system, the individual qualities of each ray are preserved. Each ray intersection making up the pattern on the plate can then be compared with the others for symmetry. Since the perforated plate contains only symmetrically spaced holes, any unsymmetry appearing in the photograph must be the result of the refractive action of the interceeding lenses.

The focusing lens is considered the lens of reference and its photographic pattern is shown in figure 4. Detection of ray shifts on the focal pattern is simpler when there are more ray paths per square cm passing through the test lens. This could be accomplished by using a grid with holes of a smaller diameter and spacing. However, such grids are difficult to construct accurately so a focusing lens was used to optically condense a larger, more easily constructed grid, down to pass the desired number of rays per $cm^2$ through the test lens.

We have tried to make several grids with small diameter holes and narrow spacing but much difficulty was encountered in producing them accurately. We therefore decided to use a commercially obtained (Radio Shack #256-1366) grid with 1.07 mm diameter holes and 2.54 mm spacing. Though this grid had larger holes and spacing than desired, the focusing lens compacted this grid to give an appropriate density of rays per $cm^2$.

Figures 5 through 11 are photographic patterns of the focusing lens in combination with each test lens. The patterns for each test lens should be compared only with the reference pattern and not with the pattern from the grid. In this way, the focusing lens pattern will be subtracted from the combined focusing lens and test lens pattern. Any resultant unsymmetry will then be due only to the effects of the test lens.

Although in this comparison process the aberrative effects of the focusing lens are theorectically subtracted, the ideal situation would be to have a focusing lens that contributed as few aberrations as possible. The use of a high quality, large diameter focusing lens would achieve this by passing more rays through the central area, significantly reducing peripheral aberrations.

## ANALYSIS

Just as the focusing lens condensed the ray pattern formed by the grid, the add or "plus" portion of each test lens is able to condense the pattern even further. Thus the higher the add power in a specific area of the lens the more dense will be the dot pattern in the particular area. This effect is shown in figures 5 through 11. It appears especially well in figures 10 and 11 since these are conventional bifocals and not progressive addition lenses. In each case however, the most condensed part of the dot pattern is in the area of highest plus power.

As the dot pattern becomes more condensed, a dark area (scotoma) develops in the area where the dots would have fallen if there were no plus power affecting the light rays. Notice in figures 5,6 and 8,9 that the lower scotoma is much larger for the +1.50 add than for the +1.00 add. In figures 5,6 and 7, part of the lower scotoma is caused by the shadow of the lens holder. Figure 4 shows this lens holder shadow. Figures 8 and 9 and AO Ultravue lenses in +1.00 add and +1.50 add respectively. These lenses were attached to the focusing lens with tape, the shadow of which appears as a dark area in the upper portion of each figure. Since no lens holder was used for figures 8 and 9 the entire lower scotoma is due to the condensation of the dot pattern by the add power.

Comparing figures 5 through 11 the distortion areas are shown by elongated dots and unsymmetrical spacing between dots. The AO and the Varilux progressive addition lenses each gave different, characteristic distortion patterns. The Varilux lens showed extreme compacting of dots on the peripheral intersection of the distance and near portions of the lens. The AO lenses give a more variable and unsymmetrical distortion pattern between the left and right side of the bifocal area than the Varilux.

Figure 10, the flattop 25, nicely demonstrates the ring scotoma effect directly around the bifocal area of the lens. If quantitative comparisons are to be made, maintaining the exact same location for each test lens and the film plane is critical as any movement of either the test lens or the film plane will change the magnification of the resultant pattern. If such movement occurs, qualitative judgments are still possible but since there is no longer an absolute reference point, quantitative analysis would be difficult.

Photographic negatives taken of patterns where exact component locations have been maintained can be superimposed and the dots in the plano sections will all be in register. This means that the negative for each test lens can be superimposed over a negative of the focusing lens pattern and deviation of the ray paths measured exactly. Such measurements will then give a quantitative measure of differences between lenses.

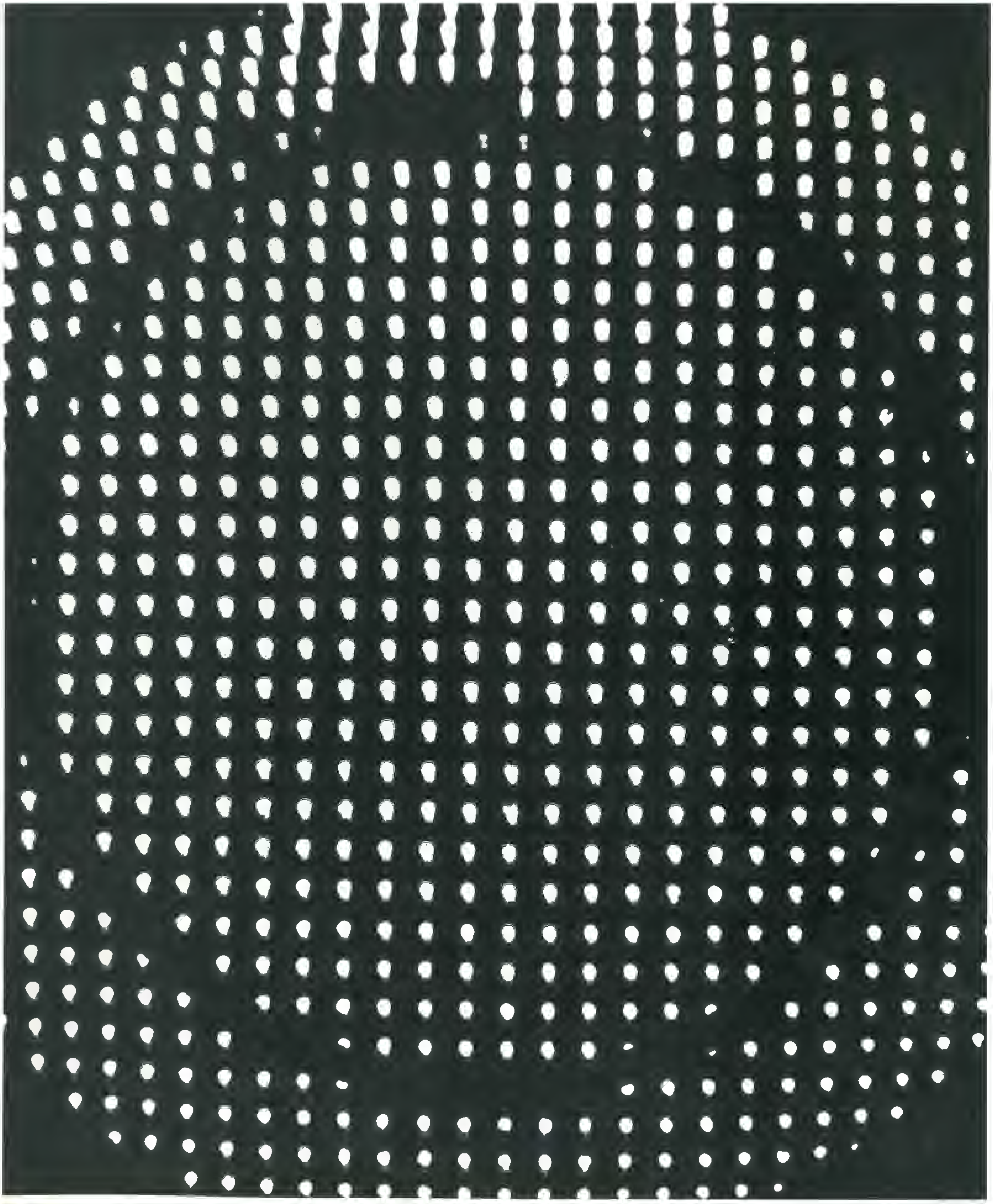

Figure #4 Center circle of dots represents image of grid through focusing lens alone; no test lens in place. Dark circle is shadow of lens holder. Dot pattern outside dark ring is the image of the grid alone. Vertical elongation and distortion of dots is a photographic artifact due to unequal illumination of the grid.

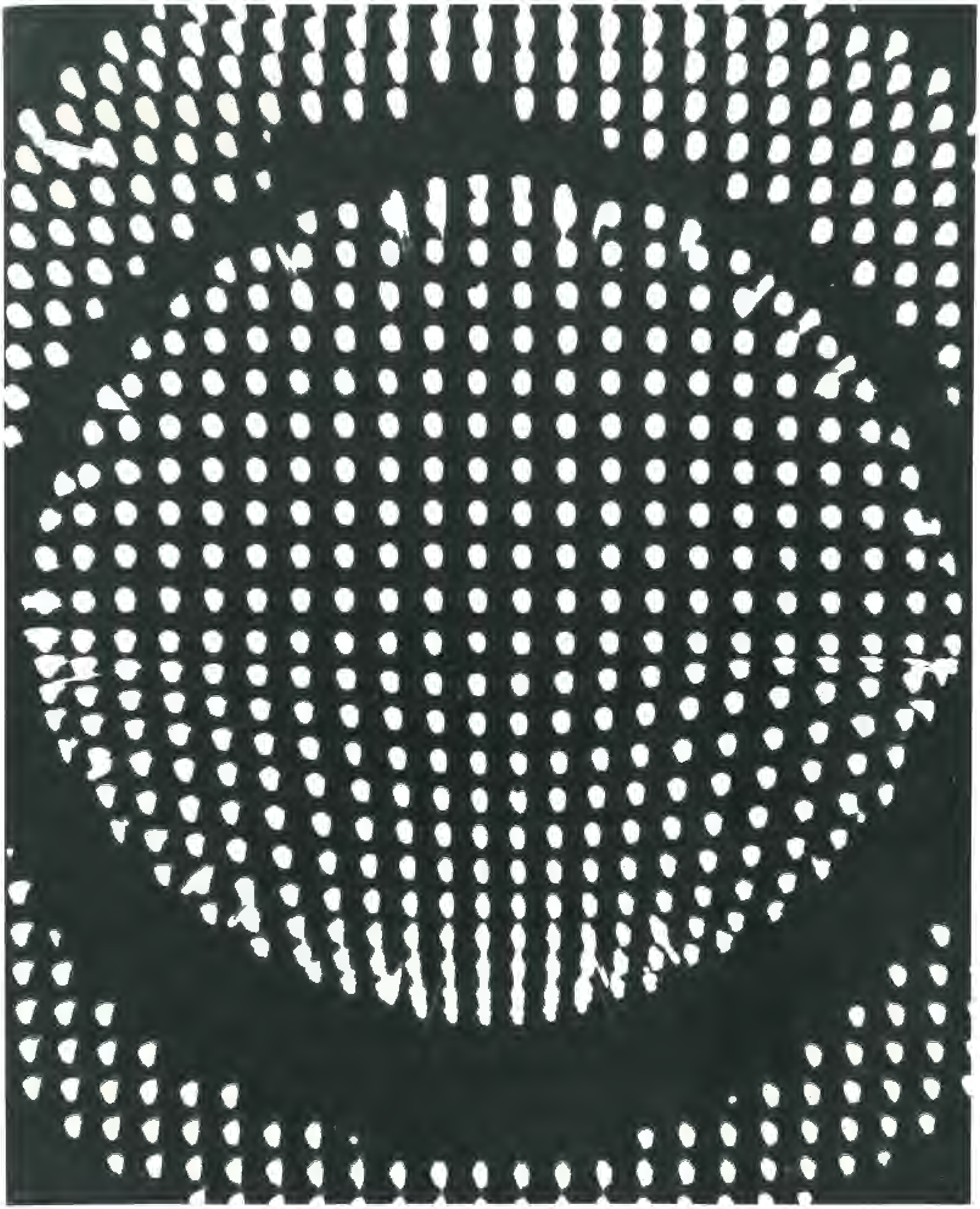

Figure #5  VARILUX II LENS, plano distance portion and +1.00 diopter add. Negative is slightly overexposed causing the dots to be larger than necessary. Dots outside the dark ring are direct images of the grid holes and have not been affected by the focusing lens.

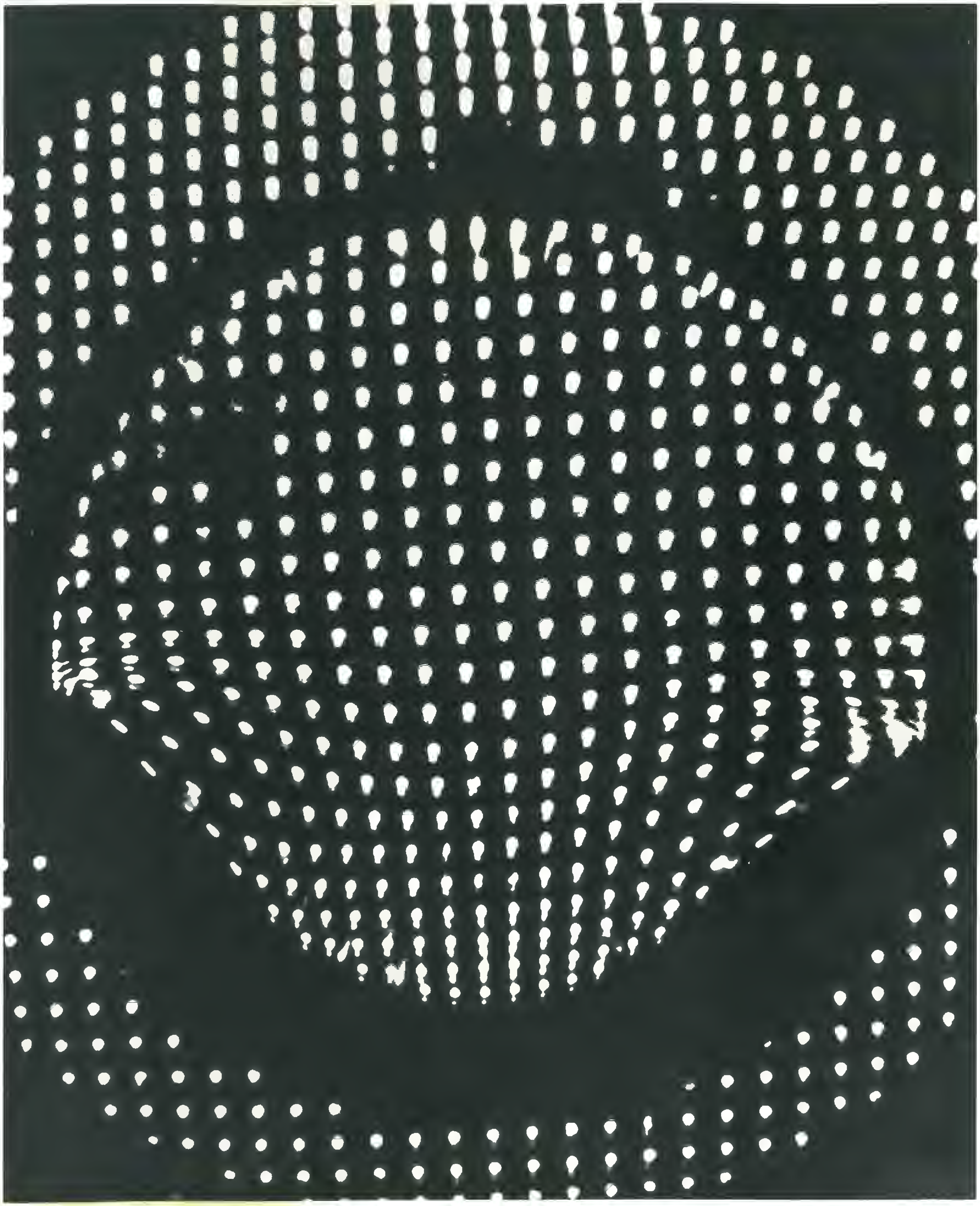

Figure #6 VARILUX II LENS, plano distance portion and +1.50 add. Dark area obscuring some dots in the upper left of distance portion is due to markings on the lens itself.

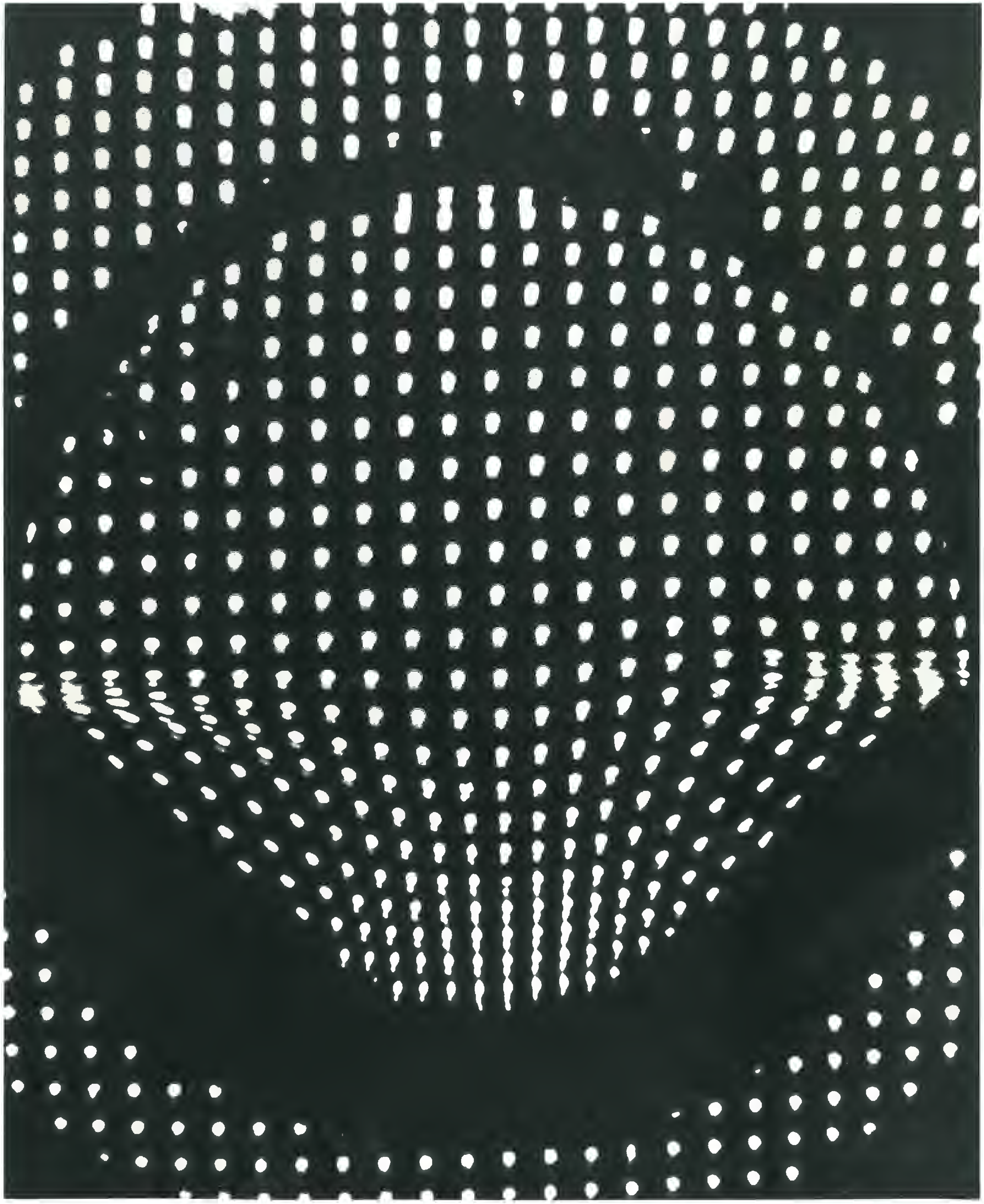

Figure #7 VARILUX II LENS, plano distance and +1.50 add but a different lens than shown in Figure #6. Dark area obscuring some dots in the upper left section of distance portion is due to markings on the lens itself.

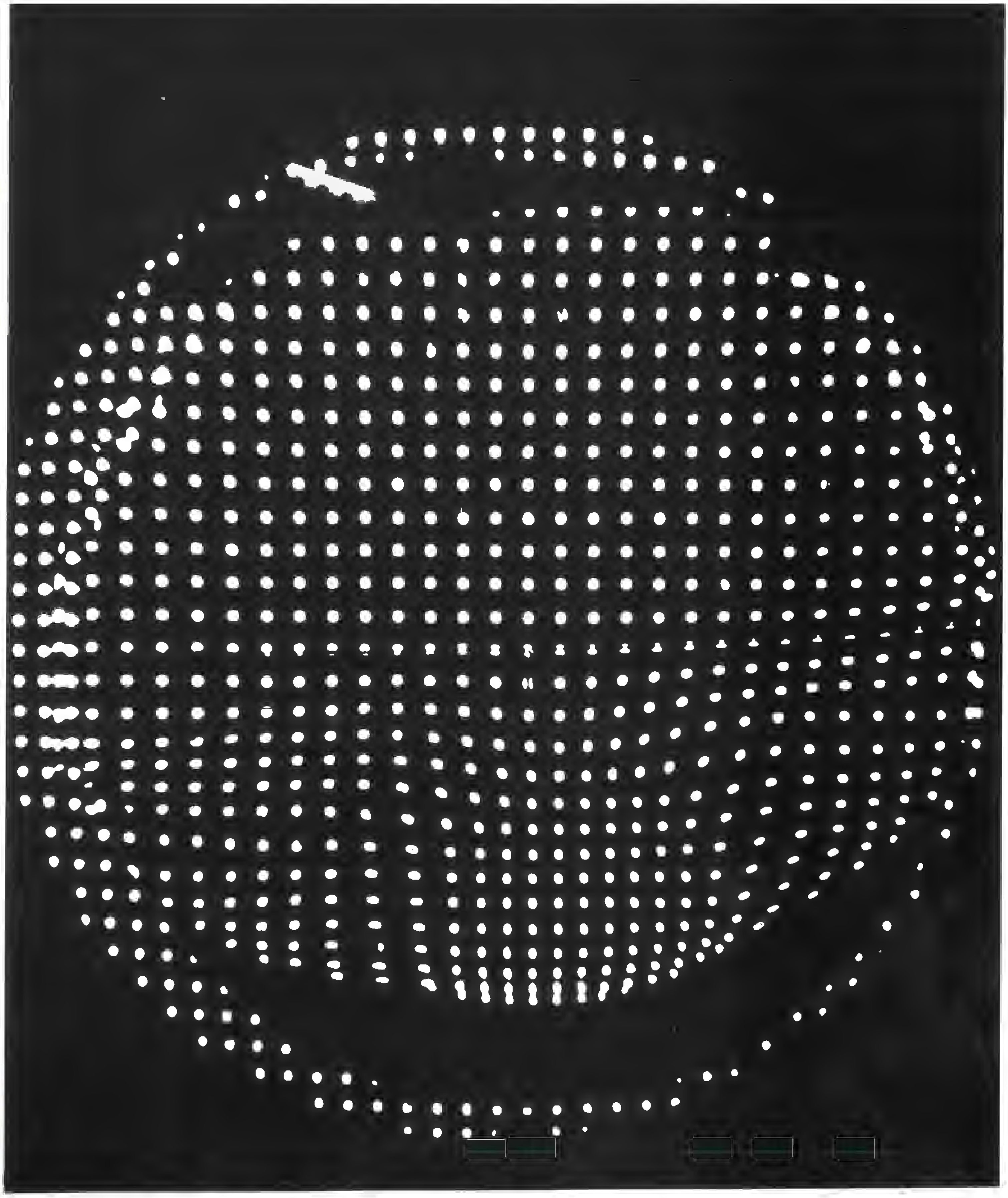

Figure #8 AMERICAN OPTICAL ULTRAVUE LENS, power -.25 Diopters sphere, +1.25 add (resultant +1.00 bifocal power). No lens holder was used with this lens so the entire lower dark area is the result of add power condensing the dot pattern. Dark crescent in the upper left is due to the tape used in mounting the lens. -.25 D power in the distance portion caused the dot pattern to expand and overlap the focusing lens pattern around the distance portion of the test lens.

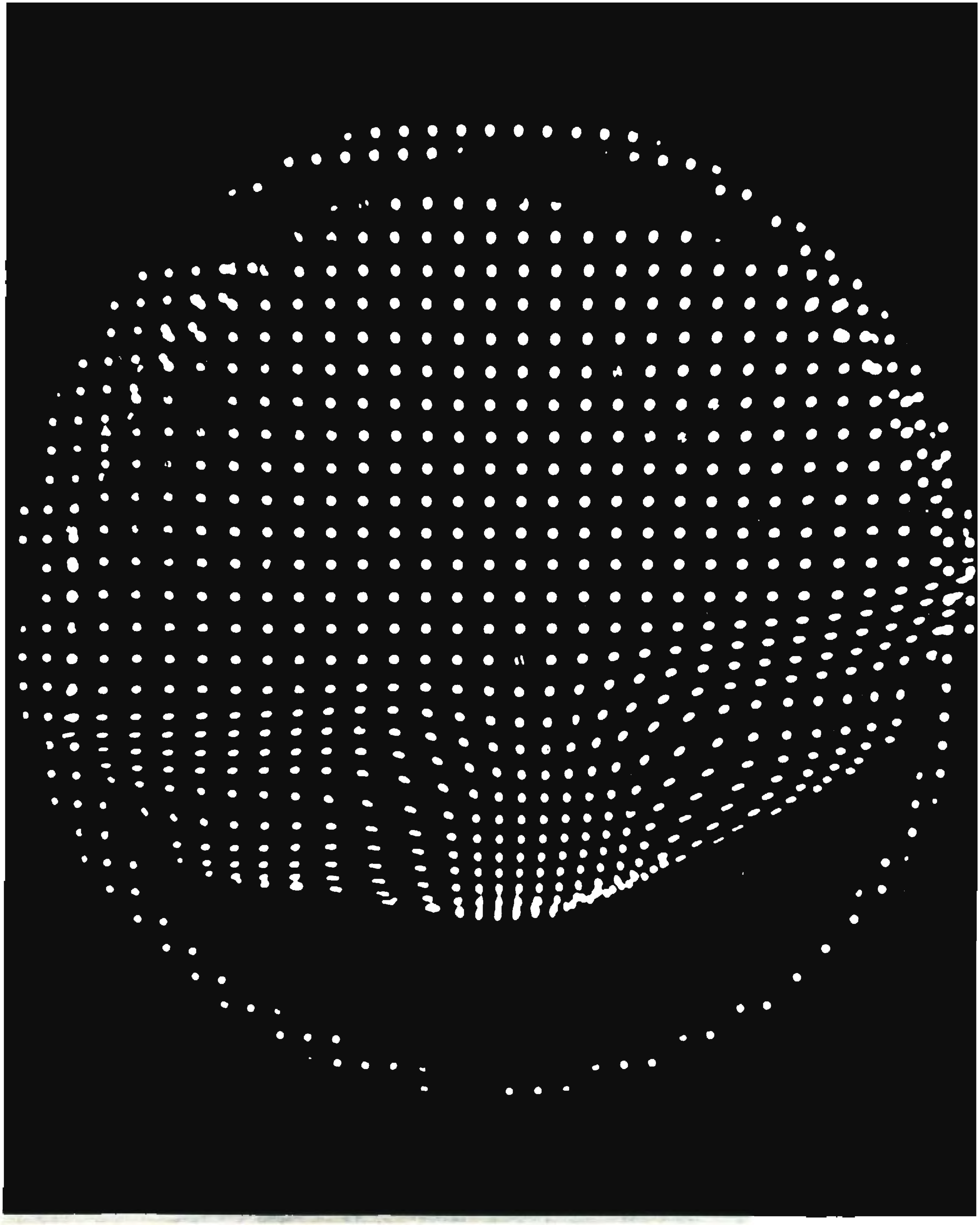

Figure #9   AMERICAN OPTICAL ULTRAVUE LENS, power -.25 Diopter sphere, +1.75 add (resultant +1.50 bifocal power). Tape used at top of lens used for mounting test lens.

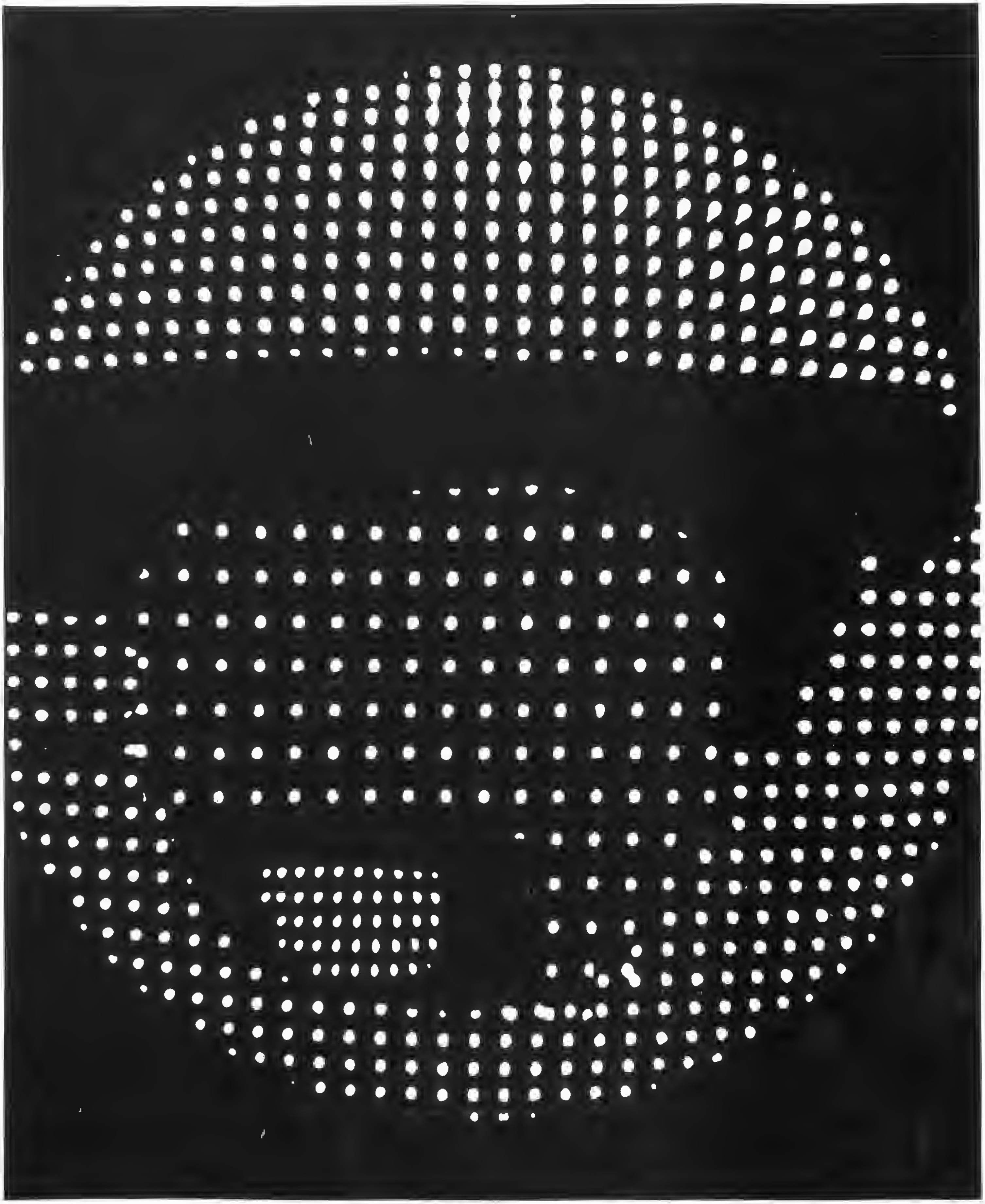

Figure #10 STANDARD FLAT TOP 25 BIFOCAL, -.50 -.75 x 180, +2.00 add. Minus power of distance portion caused expansion of dot pattern in comparison to focusing lens pattern. Lens was not removed from frame for testing. Dark band across image is shadow from the frame.

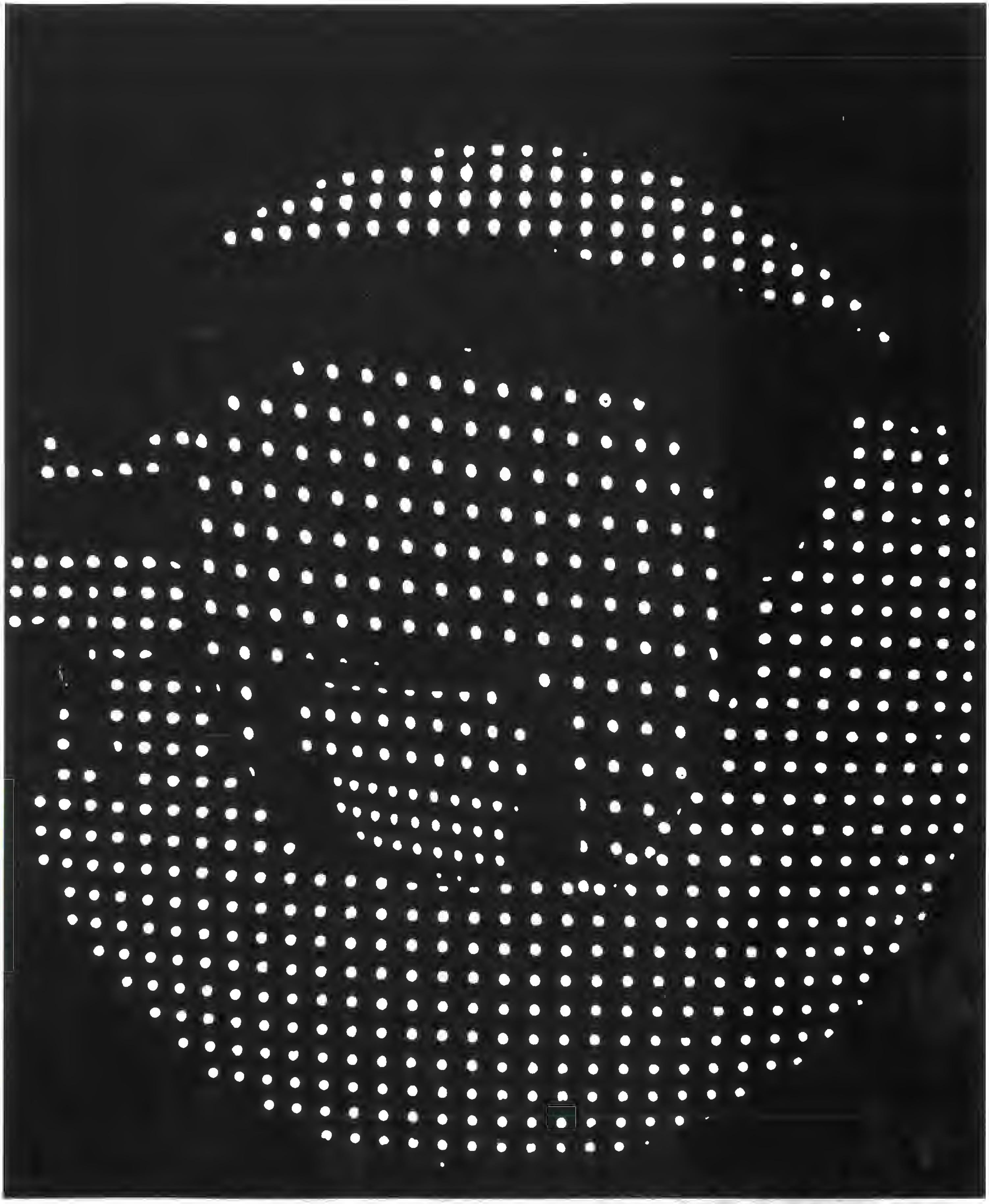

Figure #11 STANDARD FLAT TOP 25 TRIFOCAL, plano -1.25 x 20 +2.25 add. Lens not removed from frame for testing so all dark areas except around the trifocal area are due to the frame shadow. The tilt of the test lens pattern compared to the outer focusing lens pattern is a result of cylinder power in the test lens.

## SUMMARY

We have designed our experiment to demonstrate some of the unique optical properties of progressive addition lenses. The experiment is based on the Hartmann test. This is essentially a method of ray tracing which passes selected pencils of light through various portions of a lens by means of a matrix of holes placed before the lens. These pencils are interrupted by a screen and the resultant pattern can be analyzed with respect to lens power and the extent of imperfections and aberrations.

The apparatus consisted of a point light source directed toward a grid of small evenly spaced holes. The progressive addition lenses under test were placed, along with a convex focusing lens, immediately beyond the grid. A screen or photographic plate placed between the test lens and its Gaussian Focal point was then used to view or record the resultant pattern.

We succeeded in constructing a suitable apparatus to demonstrate the usefulness of the Hartmann test in analyzing various multifocal lenses and photographically documenting the Hartmann patterns of several different powers and brands of these lenses.

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