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N R L REPORT N-313

# PERFORMANCE OF INFRARED OPTICAL SYSTEMS

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N R L REPORT N-3137

# PERFORMANCE OF INFRARED OPTICAL SYSTEMS

by

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May 1947

Problem No. 37N06-14

Approved by

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#### ABSTRACT

Experimental curves were obtained which indicate the relative resolving power of various optical systems for infrared radiation from a black body whose maximum output was at a wavelength of approximately 8 microns. Spherical mirrors with and without Schmidt and Maksutov corrector plates were tested. It was found that if the field of view is less than ten minutes wide, a spherical mirror is nearly as good as the f/0.83 system with the rock-salt Schmidt plate which was tested. For larger fields the Schmidt system was better. The f/0.85 and f/0.65 mirrors tested had about the same resolving power, but for a field of view of about 12 minutes, the f/0.85 mirror with a rock-salt Schmidt plate was better than the f/0.65 mirror with a silver chloride Maksutov plate. When two detector strips subtending an angle of about 40 minutes and separated by about 25 minutes were placed at the focus of the Maksutov system, the resolution was very good. The Maksutov system gave equally good results when the receiving element was scanned across a point source by moving the mirror, and by moving the entire system.

#### PROBLEM STATUS

This report concludes the work on this problem, and unless otherwise advised by the Bureau it will be closed one month from the date of this report.

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## PERFORMANCE OF INFRARED OPTICAL SYSTEMS

## INTRODUCTION

The problem of selecting an optical system for use with an infrared detector is based on a number of considerations. If the sensitive elements are extremely small, resulting in a very small field of view, then a system with high resolving power is required. The various elements of the optical system should be of such a nature that they can be manufactured easily, accurately, and in any quantity desired.

In order to evaluate the relative merits of two systems, experimental curves were obtained by placing bolometers and thermopiles at the foci of the systems and scanning across a small chopped source of radiation while recording the amplitude of the voltage across the detector.

The source used for these measurements was a black body operated near  $100^{\circ}\text{C}$  and of such a size that it subtended an angle of one minute at the point of observation. The source was modulated 15 times per second by a square wave chopper. The radiation was collimated by a mirror having a focal length of 855 cm and the systems to be tested were placed in this collimated beam. In every case the detector was focused until maximum amplitude was obtained on an Esterline-Angus recorder.

The platform on which the optical systems were placed could be moved horizontally and vertically in steps of one minute of arc or less. Synchronous motors were used to rotate the platform horizontally and drive the recorder simultaneously so that records could be obtained automatically.

## SCHMIDT SYSTEMS

A Schmidt system with rock-salt corrector plate which has given consistently good results in an infrared ship detector was used with and without the corrector plate in obtaining data for Figures 1, 2, and 3. The detector at the focus of the optical system was a thermistor bolometer consisting of two parallel bolometer strips 0.02 cm wide, 0.1 cm long and separated from each other by 0.02 cm. The bolometer currents which resulted as the optical system scanned across the one-minute-wide

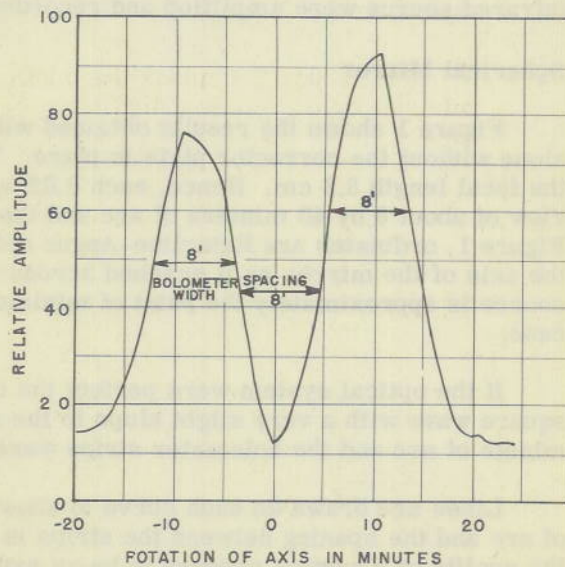


Fig. 1 - Response of 8-Minute-Wide Bolometer Strips in the Focal Plane of a 10-cm-Diameter  $f/0.83$  Spherical Mirror to Radiation from a One-Minute Source

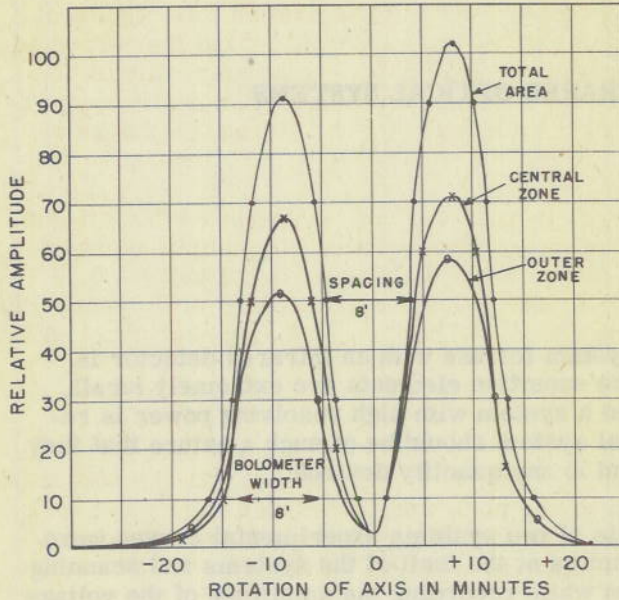


Fig. 2 - Response of 8-Minute-Wide Bolometer Strips in a 10-cm-Diameter f/0.83 Schmidt System With 1-mil Pliofilm-covered Rock-Salt Corrector Plate to Radiation from a One-Minute Source

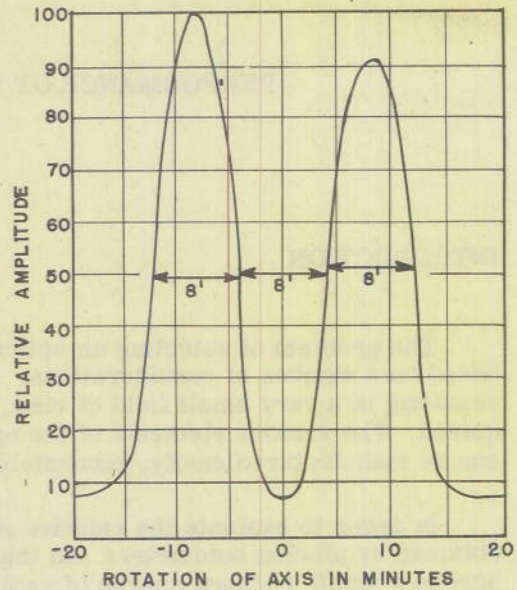


Fig. 3 - Response of a Schmidt System of f/0.83 With Uncoated Rock-Salt Plate to a Narrow Source of Radiation (From OSRD Report No. 5983)

infrared source were amplified and recorded with an Esterline-Angus recorder.

Spherical Mirror

Figure 1 shows the results obtained with the aluminized spherical glass mirror alone without the corrector plate in place. The diameter of the mirror was 10 cm and the focal length 8.3 cm. Hence, each 0.02 by 0.1 cm bolometer strip subtended a field of view of about 8 by 40 minutes of arc and the two strips were separated by 8 minutes. In Figure 1, ordinates are Esterline-Angus deflections and abscissae represent positions of the axis of the mirror as it scanned across the target. The true direction of the collimated source is approximately the point of minimum response between the two maxima in each case.

If the optical system were perfect the curve of Figure 1 would have resembled a square wave with a very slight slope to the sides since the source had a width of one-minute of arc and the bolometer strips were 8 times as wide.

Lines are drawn on each curve to show the width of the detector strip in minutes of arc and the spacing between the strips in minutes. A good criterion for expressing the quality of a system appears to be an expression for the points on the curve at which the width of the response curve is equal to the bolometer width for a single bolometer strip or the distance between the response curves of the two strips is equal to the strip spacing. In this report this quantity is given as the ratio of the amplitude at these two points to the mean amplitude of the two maxima. The matching width points and the maxima, however, are corrected by subtracting from them the noise level, which in each

case is the ordinate at the beginning of the curve. For an ideal system this "figure of merit" would be zero. In Figure 1, for example, the noise level is 12 and the corrected amplitudes of the maxima are 64 and 81, respectively, giving a mean amplitude of 72.5. The corrected amplitude of the curve on either side of the zero-rotation position where the separation of the curves equals the strip separation, is 31.5. Hence, the figure of merit is 0.435.

As would be expected, the resolution of the mirror (Fig. 1) is poorer farther off axis. Considering the two separate bolometer response curves, the ratio of the amplitude at the point where the strip width is equal to the curve width, to the peak amplitude, is 0.59 for each strip. The figure of merit for the strip width does not have as much meaning as the figure of merit for the strip separation and should not be given as much weight when comparing two systems.

#### Complete Schmidt System

Similar measurements were next made with the same mirror but with the rock-salt Schmidt corrector plate in place. The corrector plate was turned on a lathe and represents about the best that can be made on an ordinary 10-inch lathe. This is a slow process and only two or three a day can be made by a skilled worker.

Figure 2 is a resolution curve for this Schmidt system with Pliofilm cemented to the plane side of the rock-salt corrector plate to protect it from moisture. The curve labeled "total area" was obtained with the whole plate illuminated. The figure of merit for the separation of the hills is 0.51 and for the hills 0.56 and 0.54 respectively. The areas of parts inside the optical housing, such as the bolometer and its support, were next measured and disks cut so that one-half the unobstructed area on either the outer portion or the center portion of the plate could be covered. When the center zone was uncovered the results were about the same as for the total area, with the amplitude reduced of course. With radiation falling on the outer area, the figure of merit for the separation of the strips was 0.49 while for the width of the strips it was 0.58 and 0.60.

Figure 3 is reproduced from a Harvard University NDRC report\* which described measurements on a similar Schmidt system containing the same type of bolometer. It yields values of 0.48 for the separation and 0.46 and 0.51 for the strip widths. This system was of the same dimensions as the one described above, but the rock-salt corrector plate was not covered with Pliofilm.

The results of Figures 1, 2, and 3 are summarized in the first five rows of Table 1. These results mean that, near the axis, the spherical mirror produced better resolving power than the Schmidt systems. When the image is formed off axis by more than a few minutes, this is not true. For the  $f/0.83$  system under consideration the center of each bolometer strip is 8 minutes off axis. In this case the Schmidt systems were better than the spherical mirror alone as shown by the "figure of merit" 0.59 for the spherical mirror and 0.51 and 0.48 respectively, for the two Schmidt systems. Furthermore, the outer zone of one of the Schmidt systems produced a larger (poorer) figure of merit than the entire aperture.

It appears from these results that there is very little choice between a Schmidt system and a simple spherical mirror in the quality of the image formed less than

\* "Bolometer and Infrared Components," Figure 14, Harvard University, Contract OEMsr-60, OSRD Report No. 5983.

8 minutes off axis. Without question, the resolving power observed with these systems would be somewhat different for larger or smaller widths of the bolometer strip.

Comparison of Figure 2 and Figure 3 indicates that a protecting film of Pliofilm does not affect the image quality in rock-salt Schmidt systems.

TABLE I

Figure of Merit for Infrared Optical Systems  
Viewing a One-Minute-Wide 100°C Radiator

System	Field of View			Figure of Merit			Data Taken From
	Strip 1	Separations	Strip 2	From separations of the two response curves	From width of each response curve		
					No. 1	No. 2	
10-cm-diam. f/0.83 spherical mirror	8'	8'	8'	0.43	0.59	0.59	Figure 1
Same mirror with NaCl Schmidt plate covered with Pliofilm	8'	8'	8'	0.51	0.56	0.54	Figure 2
Same, central zone of the aperture open	8'	8'	8'	0.51	0.58	0.55	Figure 2
Same, outer zone of the aperture open	8'	8'	8'	0.49	0.58	0.60	Figure 2
Harvard Schmidt System, rock salt not coated with Pliofilm	8'	8'	8'	0.48	0.46	0.51	Figure 3
7.45 cm diam. f/0.65 spherical mirror	48'	30'	54'	0.58	0.51	0.43	Figure 4
Same with AgCl Maksutov plate resulting in f/0.715 system	41'	25'	45'	0.36	0.38	0.40	Figure 5
Central zone of same	41'	25'	45'	0.35	0.40	0.27	Figure 5
Outer zone of same	41'	25'	45'	0.42	0.35	0.31	Figure 5
Maksutov System with narrow field of view	11.5'	11.5'	11.5'	0.38	0.71	0.70	Figure 6
Same scanned by rotating system	44.1'	27.1'	41.8'	0.49	0.41	0.34	Figure 8
Maksutov System scanned by rotating mirror	41.8'	27.1'	44.1'	0.55	0.35	0.33	Figure 9

### MAKSUTOV SYSTEMS

The Maksutov system which was tested consisted of a spherical glass mirror and a corrector plate. The plate, pressed from silver chloride, was protected by a layer of evaporated stibnite and a layer of polystyrene film on the outer exposed surface and evaporated stibnite on the inner surface. In order to get a film of uniform thickness, the polystyrene is spun on the plate. The mirror diameter was 7.46 cm and the focal length 4.82 cm. With the corrector plate in position and focused for radiation of about 8 microns, the focal length of the system was 5.34 cm.

When focusing this system, the positions of both the detector and the corrector plate were varied until the positions for best focus were found. Three different detectors were

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used: (1) the thermistor previously described which gave a field of view 11.8 by 58.8 minutes with the two strips separated by 11.8 minutes, (2) a Harris thermopile No. 30 which had stacks 0.075 and 0.071 cm wide and separated by 0.046 cm corresponding to fields of view of 44, 41.8, and 27 minutes respectively, and (3) Harris thermopile No. 34 which consisted of a stack of eight piles 0.068 cm wide and a stack of nine piles 0.076 cm wide with the two stacks separated by 0.042 cm corresponding to angles of 40.2, 44.7, and 24.8 minutes when these units were in the Maksutov systems. These dimensions were obtained with a measuring microscope. Since the surfaces of none of these detectors were uniformly sensitive and the edges were not perfectly straight, the resulting curves are slightly ragged.

Spherical Mirror

The curve obtained using this  $f/0.65$  mirror alone and No. 34 thermopile is shown in Figure 4. This mirror had a smaller "f" ratio than the one used with the Schmidt system and comparison of Figure 4 with Figure 1 shows that the resolution is about the same as that of the Schmidt system mirror if the figure of merit for the strip width of the  $f/0.85$  mirror is compared with that for the strip separation of the  $f/0.65$  mirror. This is a reasonable comparison because the outer edge of a strip in the  $f/0.85$  mirror is 12 minutes off axis while for the  $f/0.65$  mirror the inner edge of a strip is 15 minutes off axis.

Although the thermocouple strips were wider than the bolometer strips of Figure 1, which should improve the apparent resolving power, they were also farther off axis in a

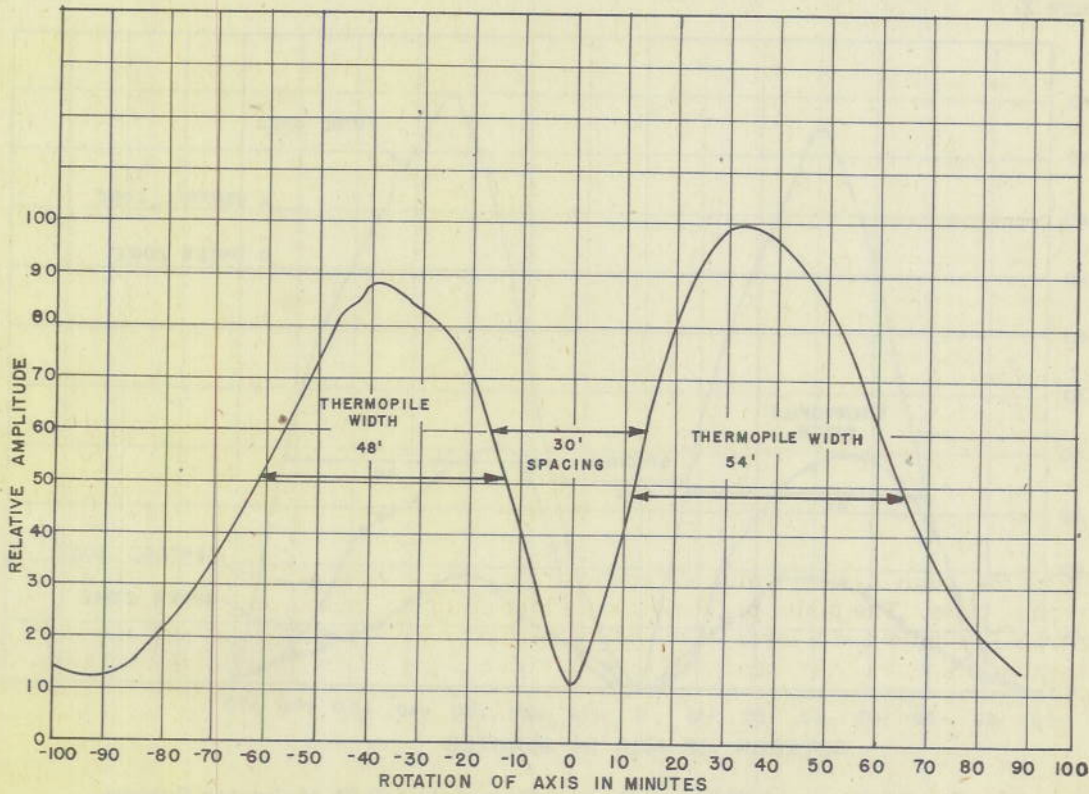


Fig. 4 - Response of a Thermopile in the Focal Plane of a 7.46-cm-Diameter  $f/0.65$  Spherical Mirror to Radiation from a One-Minute Source (Thermopile No. 34)

system of smaller "f" ratio, and this condition is unfavorable with a spherical mirror. A comparison between the two systems is made for the reason that each contained the type of sensitive element that its ultimate use required, in one case quite narrow and in the other case, quite wide. The figures of merit, derived from Figures 1 and 4, for the two spherical mirrors are compared in Table I.

Maksutov System

Number 34 thermopile was also used to obtain the curves shown in Figure 5 but with the Maksutov plate in place and focused. Two masks of such a size that the area of each was equal to one-half the total area of the Maksutov plate were cut from cardboard. One mask covered the inner half of the plate and the other the outer half. The plate was successively covered by each mask. The figure of merit for separation for the total area, central zone, and outer zone are 0.36, 0.35 and 0.42 respectively, showing that the correction was best near the center. The results for the complete system are most easily correlated by reference to the data derived from Figure 5 and shown in Table I. The relative merits of the Maksutov system and the spherical mirror may be judged by comparison of the sixth and seventh rows of data in Table I.

These results show that the correction plate produced a marked improvement of the image quality. It is thought that the figures of merit for the thermopile separation should be given more weight than those for thermopile width. It should be noted that the amplitude of the signals for the central and outer zones as compared to that for the total area is much less for the Maksutov system, Figure 5, than for the Schmidt system, Figure 2.

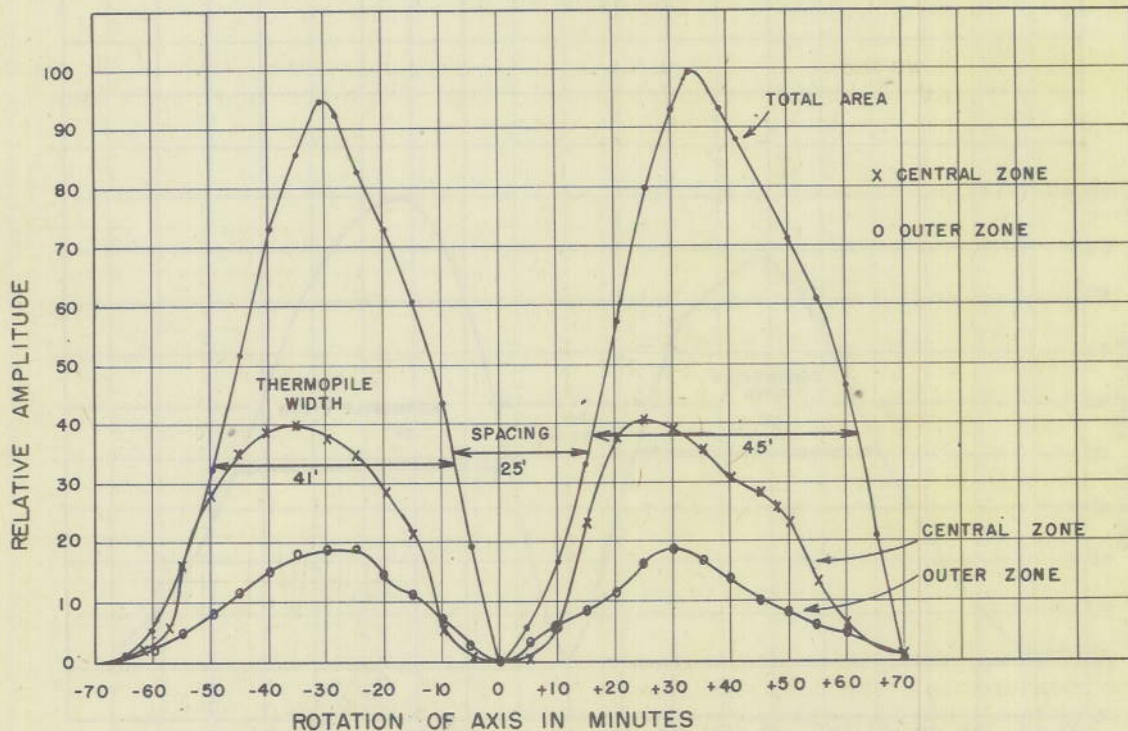


Fig. 5 - Response of Thermopile in a Complete f/0.71 Maksutov System to Radiation from a One-Minute Source (Thermopile No. 34)

### Maksutov System with Narrow Field of View

The thermistor bolometer was also placed in the Maksutov system in order to try it with a narrow field of view. Each bolometer strip subtended a field of view of about 11.5 minutes and the two strips were 11.5 minutes apart. The experimental curve is shown in Figure 6. The figures of merit derived from this curve were 0.38 from the separation of the two response curves and 0.71 and 0.70 from the widths of the two response curves. These results may be compared with the corresponding values, 0.36, 0.38 and 0.40, for the same system with the wider field of view (seventh row of data, Table I). They may be further compared with the values 0.51, 0.56 and 0.54, representing the separation of signals and width of response curves, respectively, for the same bolometer in the Schmidt system, (Figure 2).

Two methods of scanning with this system were investigated: one was to rotate the whole optical unit about a vertical axis, and the other was to rotate the mirror alone about a vertical axis while the Maksutov plate remained stationary and normal to the line of sight, this being the method for the system in one application. Figure 7 shows the resolution for three different positions of the mirror relative to the principal axis. The mirror was fixed normal to the principal axis and the system was rotated, thus obtaining one curve. Next, the mirror was rotated both clockwise and counter clockwise by steps of 10 minutes from the axis and other curves were plotted. All curves were so nearly alike that only the zero and  $\pm 60$ -minute mirror-displacement positions are shown in Figure 7. Figure 8 was obtained by placing the system in the collimated beam with the axis parallel to the beam's rays and rotating the mirror  $\pm 80$  minutes, while Figure 9 shows the effect of rotating the entire system as was done in Figures 1 through 7. Either method appears to give equally good results.

Figure 10 shows the result of focusing the system for the central zone with the outer zone covered and then plotting curves for the two zones. The center zone gave a figure of merit of 0.47 and the outer was 0.59.

Figure 11 was obtained by scanning the Maksutov system vertically across each strip of a thermistor.

It was suspected that one of the plates tested, No. 100, was warped and that it was scratched more than plate 105. In Figure 12 curve A is for corrector plate No. 105, curve B is for plate No. 100, and curve C was taken immediately after B but with the plate rotated 90 degrees. These curves show that the plates are not perfectly symmetrical.

### CONCLUSIONS

The conclusions to be drawn from these measurements are not specific because of the limited amount of data, but they should serve adequately in the design of systems with similar dimensions. Table I shows the fields of view and

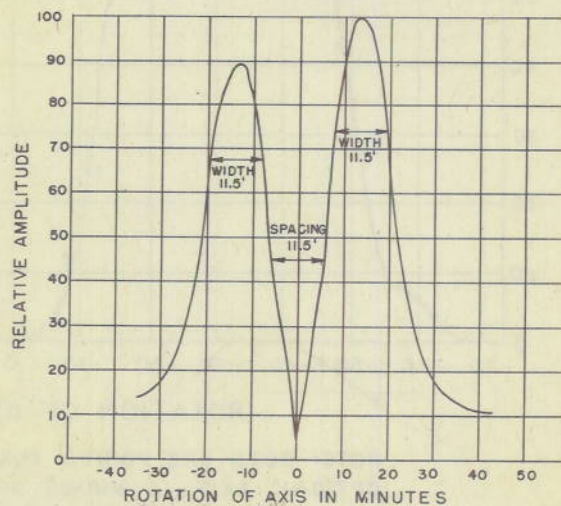
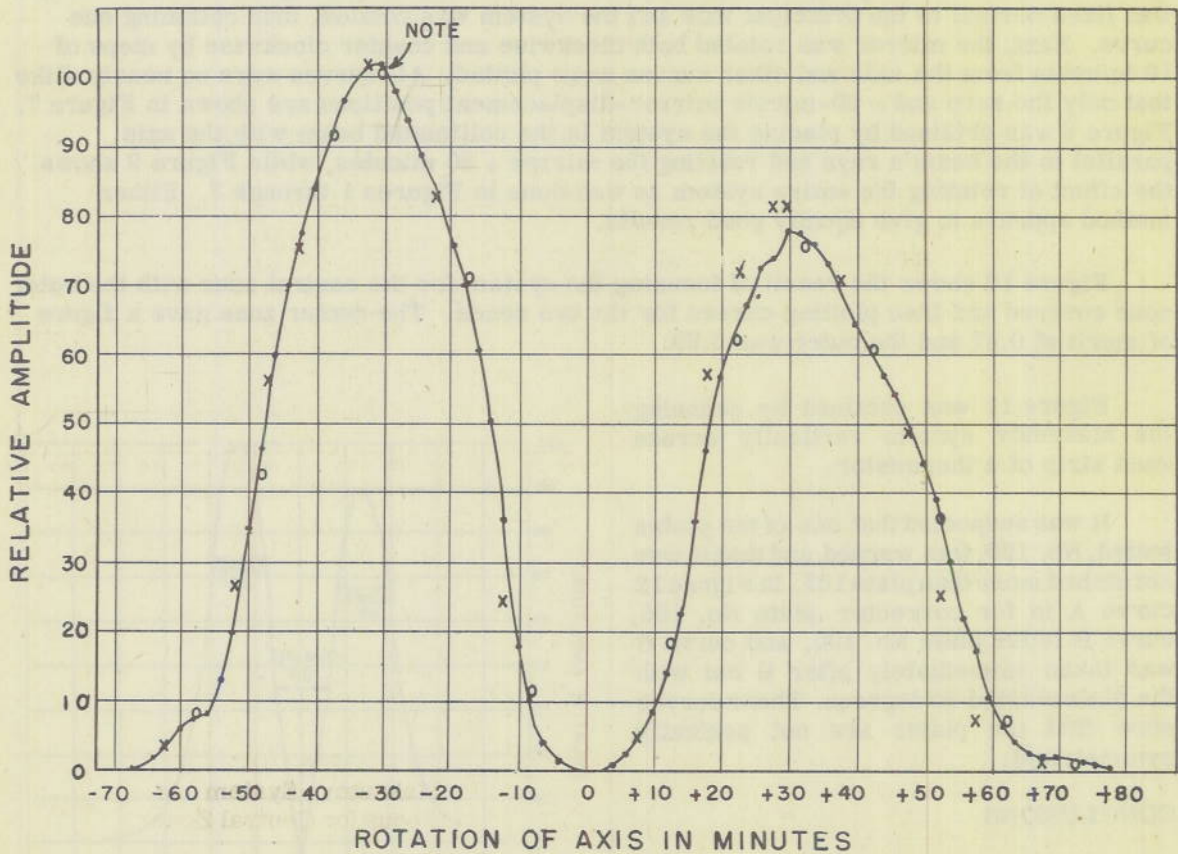


Fig. 6 - Maksutov System with Narrow Field of View

corresponding figures of merit for all the measurements represented by Figures 1 through 9, excepting Figure 7.

For extremely small fields of view, say 8 minutes, it appears that a spherical mirror is nearly as good as the Schmidt system tested, but for the larger angles the Schmidt system is an improvement. When bolometer strips subtending an angle of about ten minutes are used, a Schmidt system was much better than the Maksutov systems which were available. For a field of view of about 30 minutes or larger the Maksutov system should give good performance in actual practice.

This report should not be construed to mean that these same results will be true for the best Schmidt, Maksutov or spherical systems which can eventually be made. The results apply to existing systems which have been used as components of two devices. Much improvement in such optical systems might be achieved if the contractors who produce them could make similar measurements in order that they might learn at first hand the degree to which the optical surfaces actually produced by various methods approach the computed ideal surfaces.



NOTE: DOTS ARE POINTS FOR MIRROR PERPENDICULAR TO OPTICAL AXIS; X MIRROR ROTATED 1° FROM AXIS COUNTER CLOCKWISE; O MIRROR ROTATED 1° FROM AXIS CLOCKWISE.

Fig. 7 - Maksutov System with the Mirror at Right Angles to the Axis and Also Rotated One Degree Clockwise and One Degree Counter Clockwise (Thermopile No. 34)

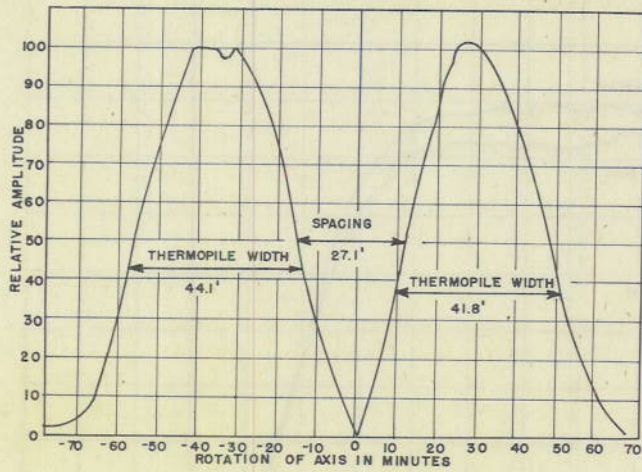


Fig. 8  
Maksutov System Scanned by Rotating Mirror (Thermopile No. 30)

Fig. 9  
Maksutov System Scanned by Rotating Whole System (Thermopile No. 30)

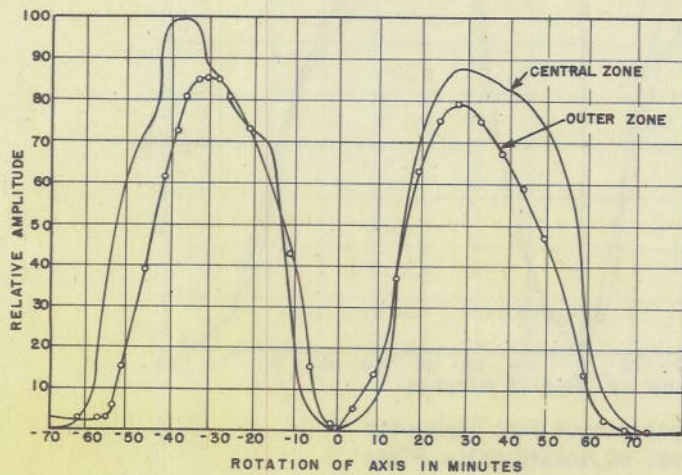
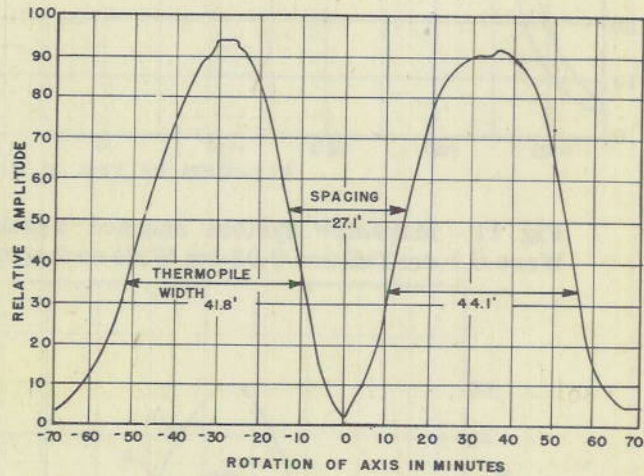


Fig. 10  
Maksutov System in Focus for Central Zone

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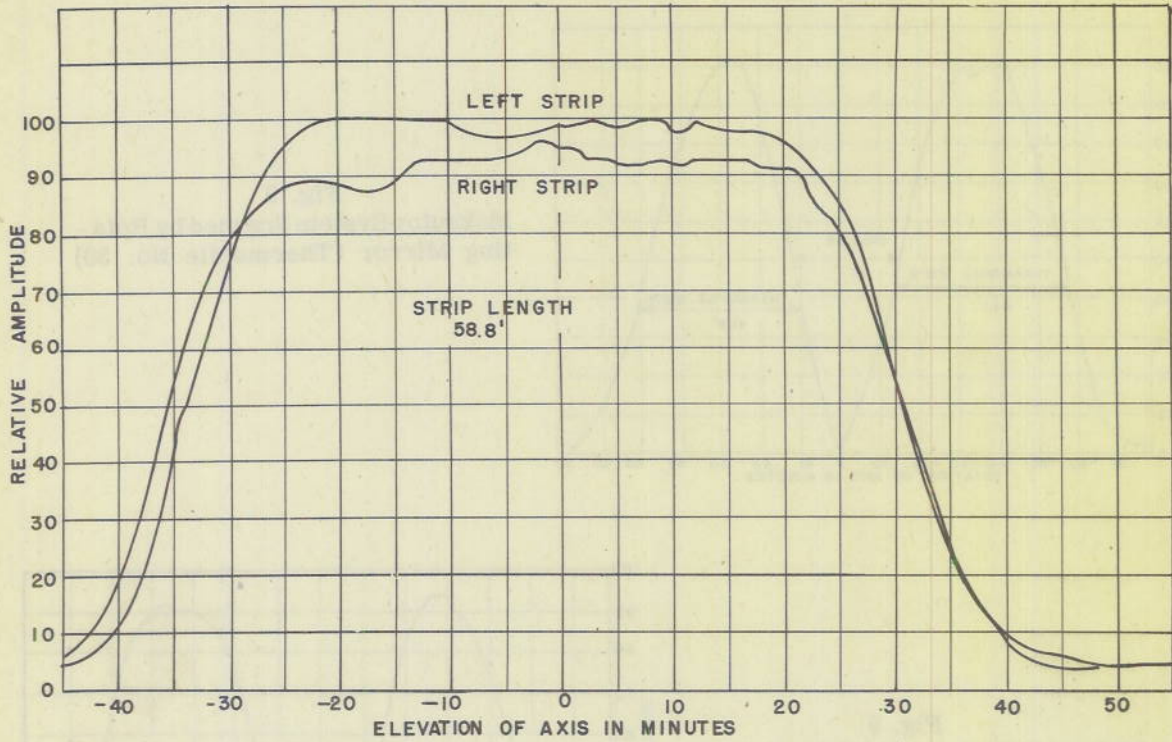


Fig. 11 - Maksutov System Scanned Vertically. The Bolometer Strips Were 0.1 cm Tall and 0.02 cm Wide so that the Field of View was 11.8' x 58.8'

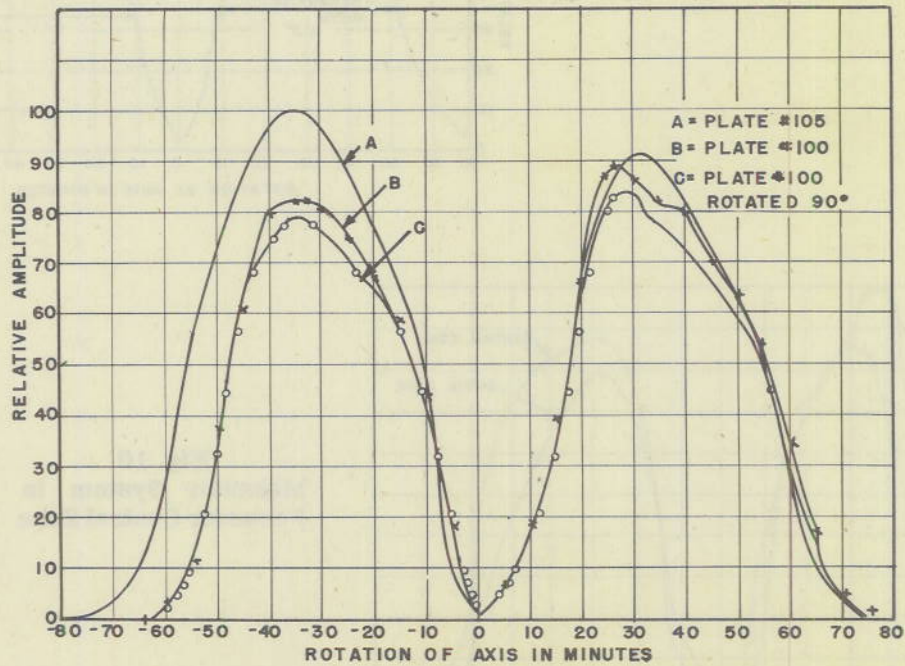


Fig. 12 - Comparison of Two Maksutov Plates and Effect of Rotating One Plate