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THE TESTING OF HELIOGRAPH MIRRORS AND THE MEASUREMENT OF MIRRORS OF LONG FOCAL LENGTH

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Abstract. The method of testing the general surface consists in observing the reflection from the mirror of a system of squares on the test board, the magnification given by the mirror being utilised to determine the curvature. The method of examination is applicable to the rapid measurement of mirrors of long focal length, especially of those forms silvered on the back, cata-dioptric mirrors, where the usual methods of measurement, test planes or spherometers, are inapplicable. Defects of curvature and distortion, astigmatism, and striae in the glass can be detected, and also defects of silvering and bad polishing.

(1) In warfare it is important that secrecy be maintained as far as possible, and as pointed out in the *Signalling Training Manual* the heliograph is capable of sending signals with a reasonable amount of secrecy if the mirror is kept nearly optically flat; under these conditions the spread of the reflected rays amounts to 98 yards at a distance of 6 miles, a spread due to the sun having a mean angular diameter of 32 minutes of arc.

(2) If the mirror is distorted or has an irregular surface the spread of the reflected rays increases at a rapid rate, the beam is scattered broadcast and the signals may be read in all directions; moreover the penetration or the carrying distance is diminished.

(3) The quality of a mirror may be tested by observing the reflection of some definite object, and a system of squares has been taken as the usual test object; the general quality of the whole surface or any part of it can then be seen by noting whether the squares on reflection appear distorted, either as a whole or locally. Such a test object may be used to give exact details of the curvature of a mirror

from which the spread and relative intensity of the reflections may be calculated at any distance.

(4) The perfect mirror is of course flat with an infinite radius of curvature, but for the purpose of examination it is desirable to impose certain limits of curvature within which mirrors may be considered satisfactory and outside of which mirrors should be rejected. The limits of curvature which have been adopted are 1000 ft radius for convexity and 500 ft for concavity; greater or less tolerance might be permitted according to circumstances, but the above limits are such as can be attained in workshop practice without straining for ultra optical performance.

(5) Now since we are dealing with unusually long focal lengths which must be rapidly measured, and further, the mirrors rarely have either side plane but in general correspond to lenses silvered on one surface, it is not practicable to use test planes or spherometers, but by making use of a magnification method, it is possible to observe both quickly and accurately whether the mirrors have focal lengths between the specified limits. For this purpose two circles are drawn on the test chart and these act as limit gauges; by taking up a suitable observing position the reflections of these circles may be optically fitted on the mirror much in the same way as any mechanical limit gauge is applied. The diameters of the circles are calculated as shown later for any diameter and focal length of mirror under test.

(6) The method of testing is as follows: The mirror is placed on an adjustable stand so that it may be directed to reflect the rays nearly along the path of incidence. The test board with its squares (usually 1 inch) and circles is set up some distance away (usually 50 ft) and facing the mirror. The test board is well illuminated and the observer stands on one side of the board and views the reflected image, using either the naked eye or a telescope the magnifying power of which may vary according to the degree of accuracy required. It is convenient, if the magnifying power of the telescope is more than six, to have an adjustable stand to hold the telescope so that the image of the test chart may be placed concentrically with the periphery of the mirror. Another convenience is an iris diaphragm fitted to the object glass end of the telescope so that full or diminished aperture may be used; the use of this will be explained later when considering the optics of the test.

(7) If the mirror is a good one, the reflection of the test board will be undistorted and along any one diameter twice the number of squares are seen as the mirror is inches in diameter plus a slight margin having a width the diameter of the objective of the observing telescope.

In Fig. 1 test rings were not drawn on the board, because in testing mirrors of various sizes it is often more convenient to have marks which are readily moveable to agree with the altered conditions of the test; such marks will be seen in the figure indicating where the circles should be drawn.

(8) If the reflection of the squares is distorted or the rings appear to lie outside or inside of the boundary of the mirror then the mirror is irregular in figure or is too concave or too convex to be satisfactory for signalling (Fig. 2).

(9) *Defective Mirrors.* There are a variety of defects in mirrors which may

make them unsuitable for signalling purposes, viz., irregularity of surfaces, bad silvering, want of glass surface polish before silvering, veins in the glass, astigmatism and curvature.

(10) *Irregular Mirrors.* The most common defect is that due to irregular surfaces; every degree can be found from that giving violent distortion, both local and general, to that exhibiting gentle undulations of the reflected test chart. The

Fig. 1. Showing the comparative appearances of good mirrors of $9\frac{1}{2}$, $5\frac{1}{2}$, and $3\frac{1}{2}$ inches diameter respectively.

Fig. 2. Appearance of the reflected squares and circles seen in irregular mirrors of $9\frac{1}{2}$ and $5\frac{1}{2}$ inches diameter.

slight undulations, often local, are usually caused by attempts to polish out sleeks and scratches, thus producing slight hollows. It is only in mirrors not optically worked that violent distortion will be found, but optically worked mirrors may spring on removal from the polishing block and assume a figure not at all desirable. The defect of irregularity is serious because, not only are the rays rendered divergent, causing loss of penetration, but all the advantages of secrecy are lost.

for the reflections may be spread over a wide angle and stray beams become separated from the main beam, allowing the signals to be read in other places than intended.

(11) *Bad Silvering*. This is a defect which, if at all serious, can be readily detected; even a poor silver film is highly reflective but the deterioration of silver films is usually progressive and its first stage needs critical examination. The light grey patches which are the precursors of decay need for their detection a somewhat subdued light, such as that reflected from a white ceiling or transmitted through translucent celluloid, but it is frequently troublesome to get the correct angle of reflection—which is somewhat oblique—that shows the spots to the best advantage.

(12) *Bad Polish, grey, short of finish*. The defect of greyness is frequently met with; it is due to silvering on a surface lacking final polishing, or polishing at too early a stage before the surface is ground fine enough. Such surfaces appear at

Fig. 3. (a) Showing effect of mirror with a vein in glass. (b) An Astigmatic Mirror.

a casual glance fairly good, but an examination of the test chart gives it an appearance of being seen through a fog and, even if the greyness is slight, crispness of definition is at once lost.

(13) *Striae*. If the glass is not homogeneous and veins or striae exist, the reflected test diagram is seen to be blurred in patches or along the course of the vein (Fig. 3 a).

(14) *Astigmatism*. Astigmatism is indicated by the image being magnified or diminished more in one direction than in another at right angles to it and also by the lines appearing intensified in one direction and grey in the other, just as when viewed through a cylindrical lens. It is sometimes advantageous to rotate the mirror, when astigmatism is suspected, in order to bring the axis of the cylindrical surface parallel to one set of lines so that the effect may be more noticeable (Fig. 3 b).

(15) *Curvature*. The radius of curvature is determined by observing the amount

the mirror magnifies or minifies. Limiting circles (see paragraph (5)) are drawn on the test chart, of diameters controlled by the specified curvatures and the observing conditions of the test. The formula for calculating the diameters of the test circles is derived as follows:

In Fig. 4 let

- $\frac{H}{2}$ = Semi diameter of mirror
 C = " " object (test circles)
 $\frac{I}{2}$ = " " image
 u = Distance of object
 v = " " image
 d = " " eye or telescope
 R = Radius of curvature of mirror
 a = Aperture of observing telescope

Fig. 4. Optical Conditions in Heliograph Mirror Testing.

From similar triangles

$$\frac{I}{H} = \frac{d+v}{d} \quad \text{and} \quad \frac{C}{I} = \frac{u}{v}.$$

Therefore

$$\frac{C}{H} = u \left(\frac{1}{v} + \frac{1}{d} \right)$$

and since the mirrors have all long radii of curvature, v will always be negative; hence by geometrical optics

$$-\frac{1}{v} + \frac{1}{u} = \frac{2}{R} \quad \text{and} \quad \frac{C}{H} = u \left(\frac{1}{d} + \frac{1}{u} - \frac{2}{R} \right).$$

If the test chart is at the same distance from the mirror as the point of observation, then

$$d = u,$$

and

$$\frac{C}{H} = 2 \left(1 - \frac{d}{R} \right)$$

from which the diameter of the object or circles just large enough to fill the mirror of radius of curvature R (with due regard to sign) can be calculated, if the observing point is small like a pin hole.

If we use a telescope of aperture a for observing, then we shall see rather more of the test board; this addition is

$a \times$ magnification of the mirror,

and since the mirror is nearly plane the formula may for all practical purposes be written

$$C = 2H \left(1 - \frac{d}{R} \right) + a.$$

(16) When testing the curvatures it is well to have a , the aperture of the telescope, small, say about 0.75 ins, because the image does not lie in the same plane as the mirror, and therefore, as focussing is done on the image, the periphery of the mirror which is used as a gauge appears out of focus if a large aperture is used. For general observation of the reflected squares an aperture of about 1.5 ins is suitable and when in doubt as to curvature the aperture may be cut down by means of an iris diaphragm in front of the object glass.

(17) It is obvious from the formula that, when the mirror is truly plane, $R = \infty$ and $C = 2H + a$, that is, the diameter of the test circle is twice the diameter of the mirror plus the diameter of objective of the observing telescope, and obviously this must be the case since the image in a flat mirror is exactly as far behind the mirror as the object is in front.

By the aid of the test diagram, knowing the diameter of the mirror under test, we can conversely determine the focal length of any mirror by noting the diametrical number of squares which can be seen in it—in effect the magnification of the mirror. This method seems very applicable to mirrors of long focal length and especially to the type of mirror silvered on the back where both refraction and reflection are involved.

(18) A comparison of the effectiveness of three different sizes of mirrors having the limits of curvature specified and also with plane surfaces is given below:

It can be shown that the divergence of the beam is given by the formula

$$\text{Divergence} = \left[\begin{array}{l} \text{Angle of incident rays} \\ \text{falling on the mirror} \end{array} + \begin{array}{l} \text{Angular aperture of the mirror,} \\ \text{i.e. angle subtended by mirror} \\ \text{at focal point} \end{array} \right]$$

Approximately the point of divergence may be taken as the apex of the mirror, but in the case of concave mirrors it is some distance in front and in convex mirrors behind.

From the above the following table is calculated for reflections of the sun (diameter = 32'), and in the case of intensity the 5 inch mirror is taken as the standard.

	3 inch			5 inch			9 inch		
	Flat	$R = +500$ ft	$R = -1000$ ft	Flat	$R = +500$ ft	$R = -1000$ ft	Flat	$R = +500$ ft	$R = -1000$ ft
Spread at 6 miles }	98 yds	109 yds	104 yds	98 yds	116 yds	107 yds	98 yds	130 yds	114 yds
Intensity of Beam at 6 miles }	0.36	0.29	0.32	1	0.71	0.84	3.24	1.84	2.39
Angular Aperture of Mirror }	—	3' 26"	1' 43"	—	5' 44"	2' 52"	—	10' 19"	5' 9"

It will be seen from the above table what an important effect curvature has upon the signals, both as regards spread and intensity, and the above figures relate only to normal incidence and reflection whereas defects of the mirror, in general, are magnified under ordinary conditions of signalling where incidence and reflection are never normal.

(19) *Effects of Frame.* Precaution should be taken to ensure that mirrors used for signalling are mounted so as to be free from flexure, which is readily caused by unequal pressure of the retaining ring or supports, thus causing distortion of the image. The glass should therefore be as thick as permissible and the mirror

Fig. 5. (a) Mirror unmounted, (b) same mirror mounted and distorted by pressure in frame.

supported on three points with corresponding antagonising springs so that the mirror can "breathe." The effect of bad mounting is shown in Fig. 5. A mirror thus distorted would scatter the signals widely and not carry as far as it is capable of doing when properly supported and indeed an ordinary commercial mirror would be as effective.

(20) The photographs illustrating this paper were taken with a telephoto lens and, in order to diminish the exposure necessary to obtain a photograph in a reasonable time, a somewhat large aperture was used, so that they are not to be taken as applying in all respects to visual observations.