COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF EXTERNAL AFFAIRS

AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITIONS

INTERIM REPORTS

11

Instruments and Methods for Auroral Observation

By

F. JACKA AND J. BALLANTYNE

ISSUED BY THE ANTARCTIC DIVISION, DEPARTMENT OF EXTERNAL AFFAIRS, MELBOURNE,
NOVEMBER, 1955

INSTRUMENTS AND METHODS FOR AURORAL OBSERVATION

by F. Jacka and J. Ballantyne

Preface 1

1. VISUAL OBSERVATIONS OF THE AURORA

Introduction 3
Identification of Forms 3
Estimation of Intensity. 4
Description of Observations 4
Accuracy of Direction Measurement 5
Timing of Observations. 6
Drawing of Skyline 7

2. AN 'OPEN SIGHTS' THEODOLITE AS AN AID TO VISUAL OBSERVATIONS

Introduction 8
Description of the 'Open Sights' Theodolite 9
Adjustment of the 'Open Sights' Theodolite 15
Conclusion 18

3. A PHOTO-THEODOLITE FOR DETERMINATION OF POSITION

Introduction 19
Description of the Photo-Theodolite 21
Adjustment of the Photo-Theodolite 30
Conclusions 34

Acknowledgements 35
References 35

PREFACE

This report describes the instruments and procedures used in the study of the aurora at the Australian National Antarctic Research Expedition's stations at Macquarie Island (61°S geomagnetic latitude) and Mawson (73°S geomagnetic latitude). It was originally written as an instruction manual for the guidance of ANARE personnel, but it is considered that the information will be of interest to others planning to participate in the 1957-58 International Geophysical Year (I.G.Y.)

Visual observations of the sort described in Section 1 carried out by observers with scientific training provide more comprehensive, accurate and intelligible records than photographs taken with an all-sky camera, especially at stations like Macquarie Island with high average cloud cover. However, during the I.G.Y. the use of an all-sky camera as well will provide 'standardized' information which is essential for the study of the aurora on a world scale.

Because of the sparseness of stations in the Southern Hemisphere, visual observations or all-sky photographs are unlikely to yeild much information on the height of the aurora; parallactic photography should be undertaken from as many stations as possible during the I.G.Y. The photo-theodolite described in Section 3 may be of interest in this connection.

F. Jacka

Senior Physicist, Antarctic Division,
Department of External Affairs.

1.

VISUAL OBSERVATIONS OF THE AURORA

by F. Jacka.

1.1. Introduction.

The purpose of the observations described below is to enable a study to be made of the relations between position intensity and form of the aurora and other physical phenomena.

Assuming a particular value for the height above sea level of the lower border of the aurora, its geographic position can be calculated from its measured elevation and azimuth. Part of this calculation is illustrated in Fig.1, which shows the angle L^o subtended at the centre of the earth by the observer and a point on the aurora of elevatio a^o for two different values of the assumed height h km. of the point above sea level.

1.2 Identification of Forms.

'The Photographic Atlas of Auroral Forms' (U.G.G.I.) is to be considered as defining the various forms of the aurora. Any additions to the terminology of this publication should be precisely defined in the records.

1.3 Estimation of Intensity.

This is to be carried out visually, the intensity being given on a scale 1 to 4. (cf. Supplement 1.2B to

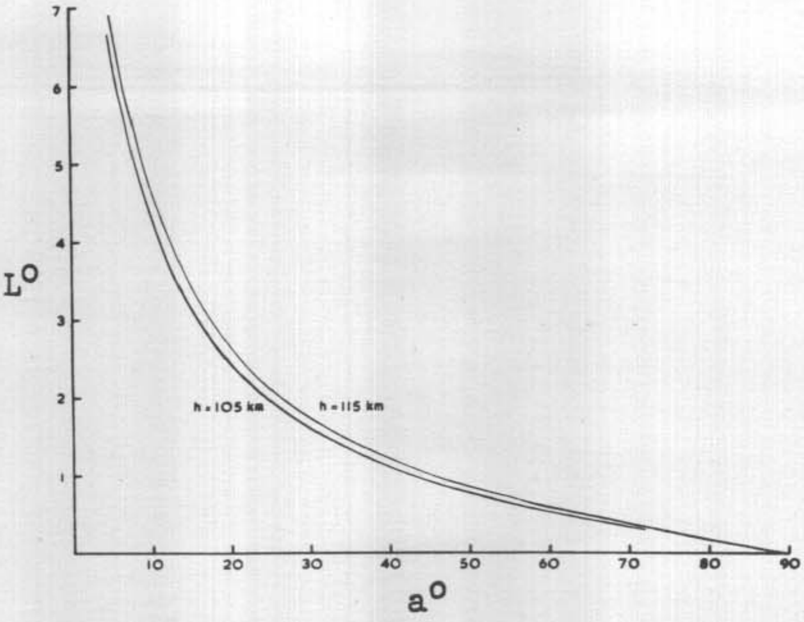
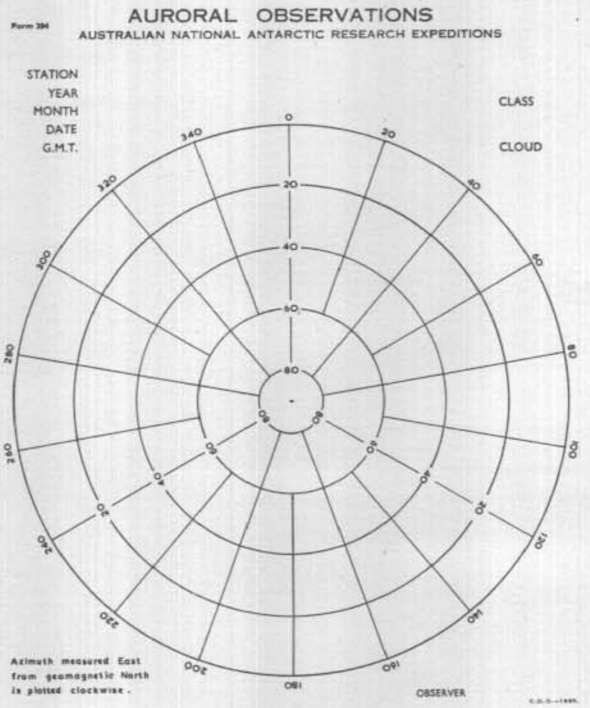


FIG. 1.

Relation between elevation a° and angle L° subtended at earth's centre by observer and aurora of height h km.



Form 204

AURORAL OBSERVATIONS

AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITIONS

STATION
YEAR
MONTH
DATE
G.M.T.

CLASS

CLOUD

Azimuth measured East from geomagnetic North is plotted clockwise.

OBSERVER

FIG. 2.

A.N.A.R.E. Form 204; actual size is 10 in. x 8 in.

'Photographic Atlas of Auroral Forms', U.G.G.I.)

1.4 Description of Observations.

If an aurora is present its position should be recorded and then the positions of all clouds should be recorded on one ANARE Form 204 (illustrated in Fig. 2) according to the following principles:-

(i) If discernible, only the lower borders of the aurora should be recorded otherwise only the outer edge (except in the case of a ray which should be represented by a line indicating its lower and upper limits).

(ii) The outlines of all clouds should be recorded and the area of cloud hatched.

(iii) The lower border of an aurora of form Q and intensity i should be denoted iQ. e.g. 2RB would mean 'band with ray structure' of intensity 2. Any colours other than the usual pale green should be noted. The direction of internal movement of rays in rayed forms should be noted.

(iv) The outer edge of a form of which no lower border is discernible should be denoted iQE.

(v) If the form Q is not identifiable write N for Q. If the form is not identifiable but ray structure is apparent write RN for Q. If the form is not identifiable but 'pulsation' is apparent write PN for Q.

(vi) If the sky is obscured by cloud but the presence of an aurora is known a note should be made on one Form 204 in the approximate position of the aurora.

(vii) Beside the heading 'Cloud' on Form 204 should be shown the fraction, in eighths, of the sky which is cloud covered.

(viii) If it is thought that the record may be incomplete because of the presence of moonlight or sunlight the symbol 'L' should be entered beside the heading 'Class' on Form 204.

If no aurora is present this fact should be recorded in a separate log book in which is entered also the name of the station, year, month, Greenwich date, G.M.T. and fraction of the sky, in eighths, which is cloud covered. If no observation is made at the usual time this fact should be recorded in the log book.

1.5 Accuracy of Direction Measurement.

With some exceptions (listed below) it is desirable to record the azimuth and elevation of the aurora and clouds to the nearest 1° if the elevation is less than 30° and to the nearest 5° if the elevation is greater than 30°. In many cases it will be possible to draw the lower borders of the aurora and outlines of cloud on Form 204 to this order of accuracy; however, if this is not practicable the actual readings of azimuth and elevation should be entered on a rough drawing.

The elevation of lower borders of the aurora on the geomagnetic meridian through the station should be measured as accurately as is practicable and the value entered on the drawing on Form 204.

When an 'arc' is present accurate measurements of it should be made. It is desirable to read the azimuth and elevation of the apex of the lower border and then the azimuth of a number of pairs of points (one each side of the apex) of equal measured elevation.

Measurements of azimuth and elevation should be made with the ANARE 'Open Sights' Theodolite (See Section 2) which is direct reading to 1°; interpolation to 0.1° is practicable.

1.6 Timing of Observations.

Under normal circumstances observations should be made every 1/4 hour commencing on the hour G.M.T. The aurora should be observed first and then the cloud. The time recorded on Form 204 beside the heading 'G.M.T.' should be the mean, to the nearest minute, of the period of observation of the aurora.

Whenever the auroral display consists entirely of 'arcs' (single or multiple) or of a single simply-shaped 'band' and the meteorological conditions are suitable, observations should be made at such intervals as will enable a more or less continuous record to be kept of the display. Observations every 5 minutes will usually suffice. Observations on the display should be continued for 30 minutes after the arc or band breaks up or disappears. An attempt should be made to give a detailed account of this break up or disappearance and its time should be accurately noted.

On two or three nights of each month (including all 'World Days') if suitable meteorological conditions prevail, an attempt should be made to keep a more or less continuous record of the aurora throughout the night. Observations every 5 minutes while the aurora is present will usually suffice. Timing of these observations should be as accurate as possible.

1.7 Drawing of Skyline.

At some time during the year a drawing should be made, on one Form 204, of the skyline as seen from the observing site.

2.

AN 'OPEN SIGHTS' THEODOLITE AS AN AID TO VISUAL OBSERVATIONS OF THE AURORA

by F. Jacka and J. Ballantyne.

Abstract

A simple theodolite with 'open sights' suitable for measurements of azimuth and elevation of points on the aurora to an accuracy of 0.1° is described. The operation of sighting and reading scales can be carried out in about 5 seconds.

2.1 Introduction.

The difference L° in geomagnetic latitude between an observer and a point at elevation a° on the lower border of an aurora at height h km. in the geomagnetic meridian of the observer is given by

$$\cos(L+a) = (1 + h/R)^{-1} \cos a$$

where R = 6360 km. the radius of the earth.

Assuming h = 105 km. the range of latitude of lower borders of auroras visible from any one station near the auroral zone is about 20°.

For purposes of statistical analysis of variations in latitude of the aurora and their dependence on other phenomena it is desirable to divide the latitude range into about 20 units. For this reason it is considered that the latitude should be specified to the nearest 1°, which for auroras just above the horizon necessitates that the elevation be measured to the nearest 1°. There is little point in making more accurate observations, since an error of about 0.5° in the latitude determination is introduced by an error of 10 km. in h. (From Northern Hemisphere observations it appears that the probability of occurrence of auroral lower borders at heights outside the range 105 ± 10 km. is about 0.5).

In determining the orientation of an aurora relative to the geomagnetic meridians, errors in the assumed height are not so important and since the orientation of say 'homogeneous arcs' changes only slightly (e.g. with time of night) it is desirable to make somewhat more accurate measurements of direction when practicable.

The theodolite described below is intended for measurements such as those considered above and can be read directly to 1° in elevation and azimuth; estimation to 0.1° is easily carried out. (Reading of azimuth to 0.1° is rarely required but is not inconvenient).

Because of movement of the aurora rapid sighting and reading of scales is of first importance.

2.2 <u>Description of the 'Open Sights' Theodolite.</u>

A general view of the 'Open Sights' Theodolite is shown in Fig. 3; details of construction are illustrated in Figs. 4a and 4b. The main features of the instrument are described below.

(a) The Azimuth and Elevation Bearings:- The azimuth bearing consists of two deep-groove single-row ball bearings fitted one on top of the other into an inverted cup (the azimuth bearing cup) which forms the bottom of the instrument body. This rotates on the vertical spindle which is fixed to the levelling base.

The elevation bearing consists of self-aligning ball bearings housed in the elevation bearing blocks which are each held by screws into the instrument body. The holes in the body through which the screws pass are 'drawn' to enable adjustment of trunnion heights.

A felt brake washer, clamped between a flange on the vertical spindle and the brake plate (which screws into the azimuth bearing cup) serves to damp the movement of the bearing. A similar device is fitted on one side of the elevation bearing. These 'brakes' do not hinder sighting to an accuracy of 0.1° but effectively prevent free movement once the direction is set.

(b) The Levelling Device:- Conventional foot screws with hemispherical 'feet' are used for levelling; these fit in a cone, V groove and plane machined in the base plate which also serves as the bottom of the

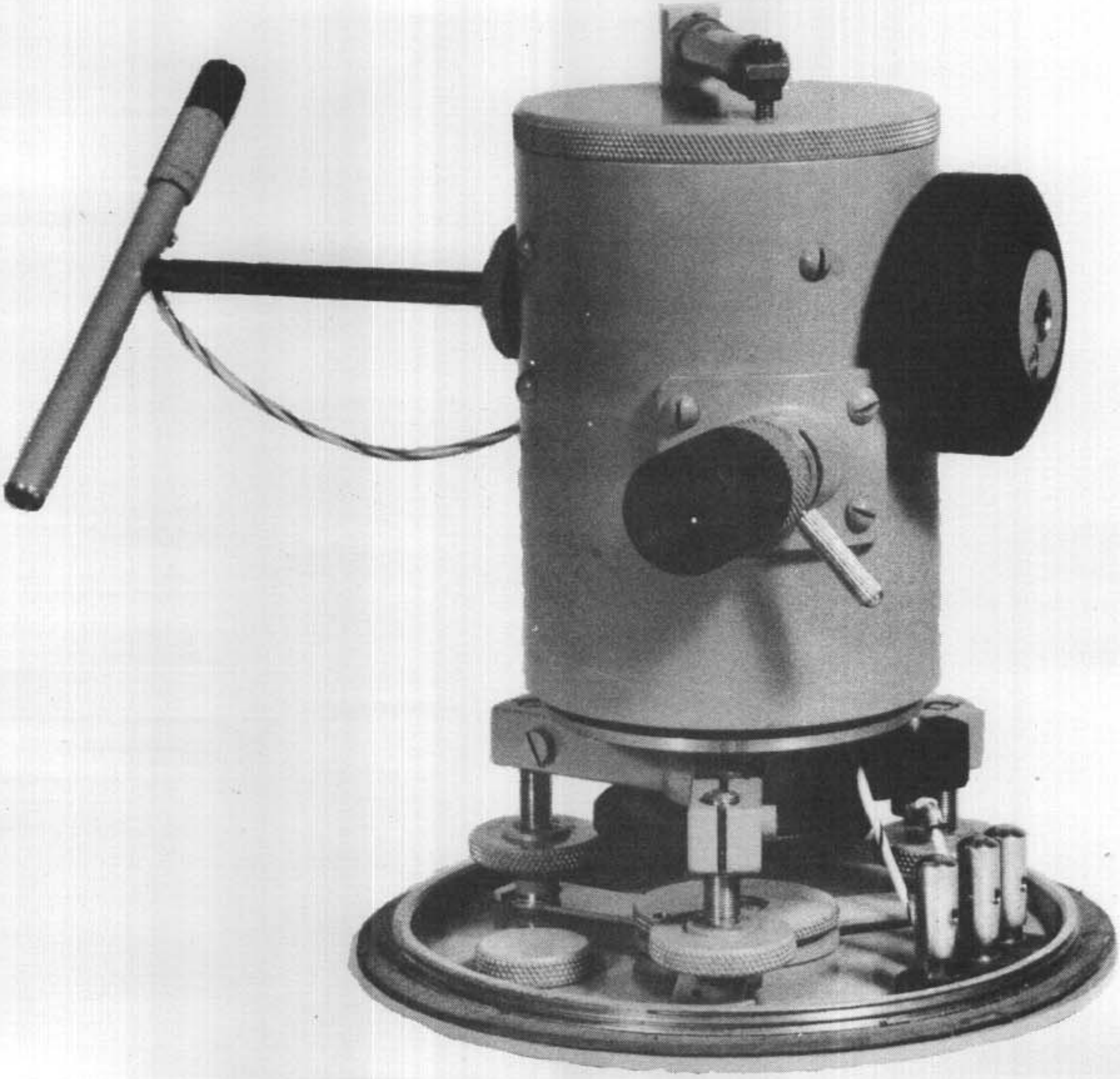


FIG. 3.

General view of the 'Open Sights' Theodolite.

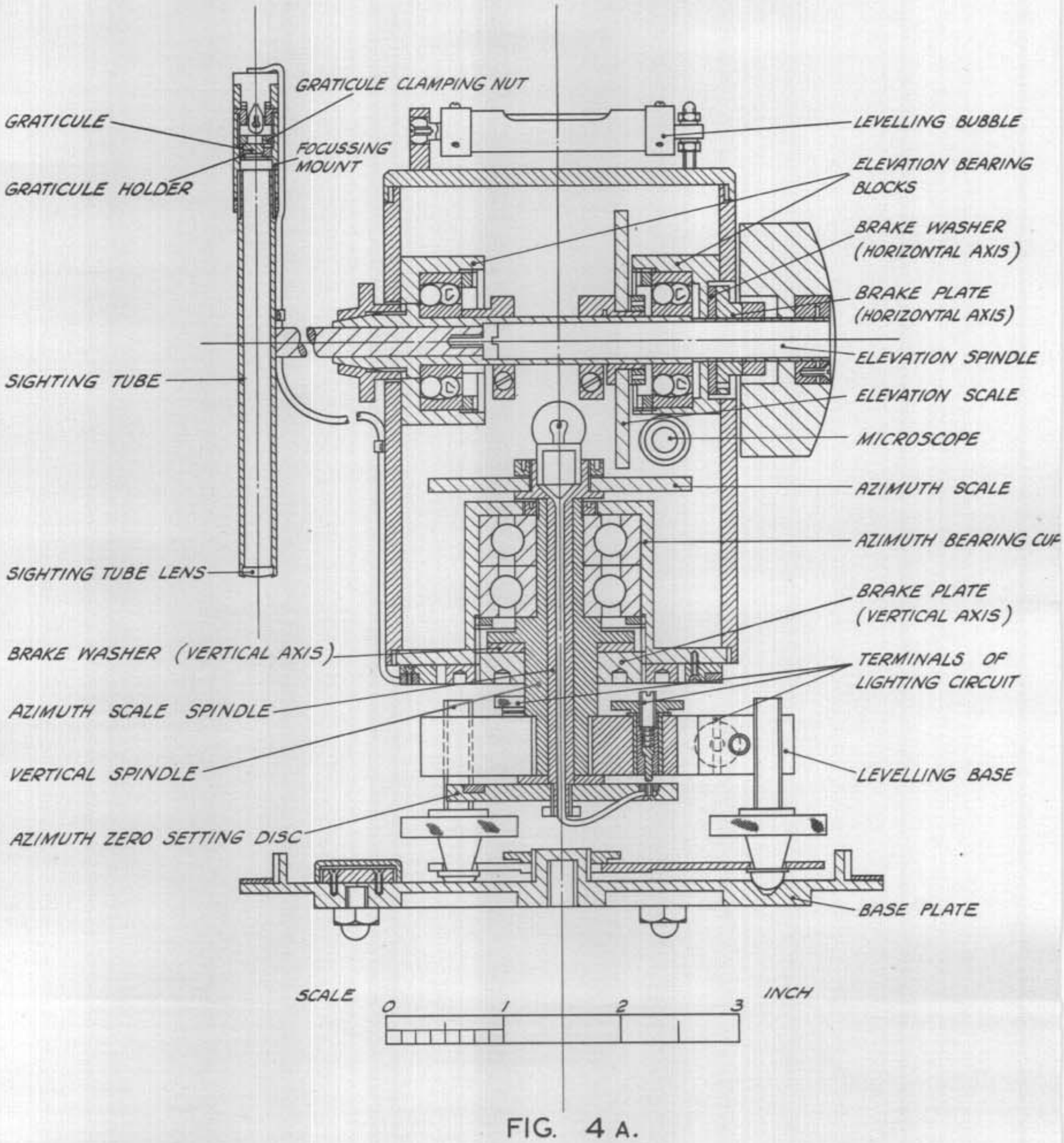


FIG. 4 A.

ELEVATION OF THE 'OPEN SIGHTS' THEODOLITE.

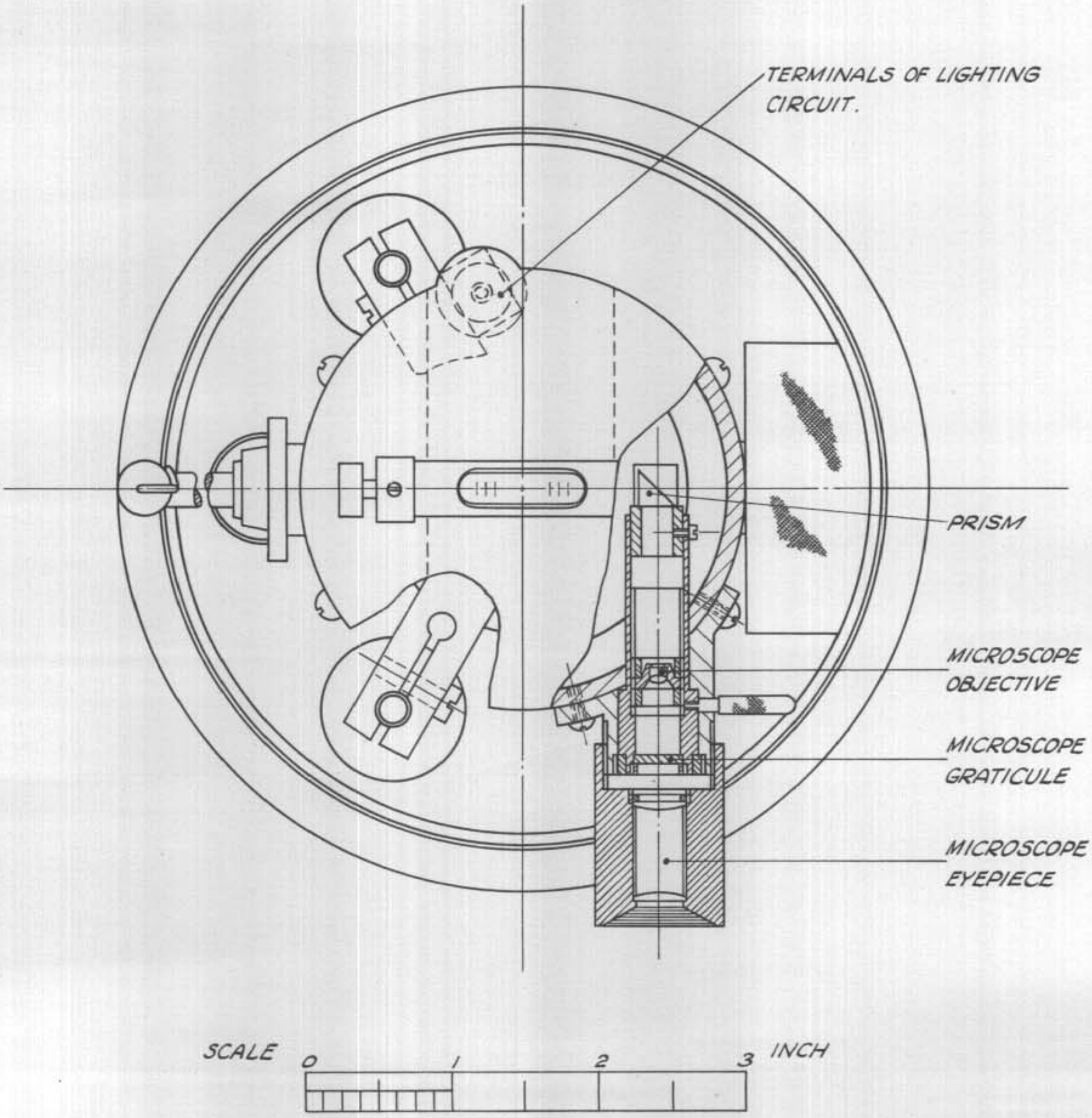


FIG. 4 B.

PLAN VIEW OF THE 'OPEN SIGHTS' THEODOLITE.

carrying can.

The levelling bubble which is mounted on the top of the instrument has a sensitivity of 3.5 minutes per 2 mm. division.

The instrument is held down to the base plate by a three-limbed phosphor bronze plate which fits over the 'feet' of the foot screws and is pulled down in the centre by a nut screwing onto a spigot in the centre of the base plate.

(c) The Azimuth and Elevation Scales:- The azimuth and elevation scales, which are identical, are etched on glass discs 1/8 in. thick. The scales of 2 in. diameter, are graduated in 1° intervals and figured at 10^0 intervals.

The azimuth scale is mounted on a spindle which passes through the vertical spindle and is fitted on the bottom with an ebonite disc which can be rotated to enable zero setting of the azimuth scale.

A brass ring pressed into this ebonite disc acts as a slip ring to enable electrical connection between an insulated spring-loaded contact which bears on it and forms one terminal of the lighting circuit and an insulated wire which is fixed to the slip ring and passes through the centre of the azimuth scale spindle to a small torch globe which screws into the top of this spindle. The other terminal of the lighting circuit is fixed directly to the levelling base.

In order to achieve uniform lighting of the scales the inside of the instrument body and the back surfaces of the scales are painted flat white.

(d) The Scale Reading Microscope:- The scales are read through a microscope, giving approximately 5 diameters magnification, mounted through the body of the instrument. The objective is an achromatic doublet of focal length 0.41 in., the eyepiece a Ramsden eyepiece with components of 1 in. focal length. The scale index graticule is a single diametral line on a glass disc. A right-angled prism is mounted in front of the microscope objective.

The tube carrying the prism, objective and scale index graticule can be rotated through 90° by means of a small lever to enable reading either the azimuth or the elevation scale.

(e) The Sighting Tube:- The sighting tube consists of a tube carrying a single lens of 90 mm. focal length 'spun' into one end and a cross graticule mounted in the focal plane of the lens at the other end. To sight on a point the instrument is turned by means of the large ebonite knob on the end of the elevation spindle to bring the image of the cross as seen with the right eye coincident with the point as seen with the left eye.

Such a device can be used by any observer with binocular vision; however, errors are possible with some observers. If the axes of the eyes are parallel, (when the field of view of the left eye is substantially different from that of the right eye and the eyes are focussed at infinity), then no error will be made in sighting. However, if the axes of the eyes converge or diverge in the horizontal plane (conditions known as esophoria and exophoria) then errors may be made in azimuth. If the right eye diverges up or down relative to the left eye (conditions known as hyperphoria and hypophoria) errors may be made in elevation setting. These conditions are quite common.

In order to avoid errors of this type the diameter of the sighting tube has been made small (5/16 in.) and it is mounted on a thin shaft (1/4 in. diameter) extending out 3 in. from the instrument body. If then the eye is held a few inches back from the lens these parts of the instrument obscure only a small fraction of the field of view of the right eye. The fields of view of the two eyes are then substantially similar and no difficulty was experienced in sighting to within 0.1° by about ten different observers tested.

The use of a long shaft to carry the sighting tube clear of the instrument body also enables high elevation readings to be made easily. This shaft is clamped in a pin chuck in the elevation spindle; it may be rotated in the chuck to enable elevation zero setting.

The sighting tube graticule consists of a black cross, with 0.005 in. line thickness, on a glass disc. It is illuminated by a small globe screwed into the focussing mount. The lighting circuit is made through the body of the instrument and a slip ring on the under-side of the azimuth bearing cup which is contacted by a spring-loaded pin mounted in an insulating block fixed to the levelling base. The graticule is mounted eccentrically in its holder to enable adjustment to 90° of the angle between the sighting tube axis and the trunnion axis (the horizontal mechanical axis.) This holder is carried in a focussing mount which screws over the outside of the sighting tube and is clamped by a locking ring.

(f) The Instrument Cover:- The instrument is protected when not in use by a metal cover which screws over the base plate. This also serves as a carrying case. Before fitting the cover, the shaft carrying the sighting tube must be pushed into the hollow elevation spindle and the eyepiece of the scale-reading microscope must be removed; this is replaced by a metal cap to protect the scale index graticule.

The instrument is mounted on a tripod or a steel pipe fixed in concrete. It is left in position when not in use.

(g) Lubrication:- All bearings and felt brake washers are greased with Mobil Grease Aero Lo-Hi (a lithium base grease satisfying British Specification DTD 577) and perform satisfactorily at -50°C.

2.3 Adjustment of the 'Open Sights' Theodolite.

The following procedure is devised to enable adjustment of the 'Open Sights' Theodolite in the field.

(a) Bubble Adjustment and Levelling:- Call the foot-screws A.B.C. With the bubble parallel to AB, centre the bubble using A and B. Rotate the instrument through 180° in azimuth. By adjustment on the bubble mount halve the error in bubble centering, then centre by use of A and B.

Rotate the instrument through 90° in azimuth. Centre the bubble by use of C only.

Repeat these steps till the bubble is centred for all azimuth settings.

(b) Focussing the Sighting Tube:- Sight on a distant object. Screw the focussing mount of the sighting tube in or out till there is no parallax between the image of the graticule as seen with the right eye and the distant object as seen with the left eye. Tighten the locking ring to prevent further movement of the focussing mount.

(c) Test for Eccentricity of the Azimuth Scale:- Sight on a distant object (at least 1000 feet) of roughly zero elevation. Read the azimuth a_1. Transit the sighting tube (i.e. turn through about 180° in azimuth and in elevation) and resight on the distant object. Read the azimuth a_2. Note the difference $(a_2 - a_1)$. Turn the azimuth scale through 45° and repeat the above steps. Again note $(a_2 - a_1)$. Turn the azimuth scale through a further 45° and repeat.

The three values of $(a_2 - a_1)$ should be equal. If they are not, the azimuth scale is eccentrically mounted and must be adjusted.

(d) Angle between the Sighting Tube Axis and the Trunnion Axis:- This angle should be 90°. If this is correct, $(a_2 - a_1)$ will be 180°. If it is not, the graticule of the sighting tube must be shifted radially as follows. Remove the graticule clamping nut; the graticule holder can then be rotated, producing a radial movement of the centre of the graticule which is eccentrically mounted. The graticule must then be rotated in its holder to bring the graticule lines into positions at 45 ° to the vertical. Replace the graticule clamping nut.

Repeat this procedure till $(a_2 - a_1) = 180^\circ$.

(e) Test for Eccentricity of the Elevation Scale:- Sight on a distant object of roughly zero elevation. Read the elevation e_1. Transit the sighting tube and resight on the distant object, Read the elevation e_2. Note $(e_2 - e_1)$. (The true elevation should be given by $2e_o = 180 - (e_2 - e_1)$ but this need not be measured). Turn the sighting tube through about 45° relative to the elevation scale and repeat the above operation. Again note $(e_2 - e_1)$. Turn the sighting tube through a further 45° relative to the elevation scale and repeat.

The three values of $(e_2 - e_1)$ should be equal. If they are not, the elevation scale is eccentrically mounted and must be adjusted.

(f) Test for Slope of the Trunnion Axis:- Sight on a star of elevation about 80°. Read the azimuth a_1. Transit the sighting tube and after a measured interval of time (say 20 seconds) resight on the star. Read the azimuth a_2. Again transit the sighting tube and after a further 20 seconds resight on the star. Read the azimuth a_3.

If the trunnion axis is horizontal $a_2 - (a_1 + a_3)/2$ is approximately 180°. At an elevation of 80° the maximum error in this equation which should be tolerated is 0.4°. If the error is greater than 0.4°, the trunnion axis slope should be corrected by making a vertical movement of the elevation bearing situated at the opposite end from the sighting tube.

Before using the instrument it is necessary to sight on an object of known azimuth and elevation and then to set the scales to read the correct values,

2.4 Conclusions.

The 'Open Sights' Theodolite described is in use at Macquarie Island and has proved to be reliable and simple to operate. The operation of sighting on a point on the aurora and reading the scales to 0.1° takes about five seconds.

3.

A PHOTO-THEODOLITE FOR DETERMINATION OF POSITION OF THE AURORA

by F. Jacka and J. Ballantyne.

Abstract.

A photo-theodolite for determination of position of the aurora and suitable for Antarctic use is described.

With this instrument, the azimuth and elevation of the centre of a photograph of the aurora are read directly to an accuracy of 1 minute on scales graduated at 2° intervals. The direction to any other point in the picture can then be computed from its coordinates in a grid reproduced on each picture and the previously measured distortion characteristics of the lens.

The lens used has a focal length of 5 cm. and an aperture f/1.5. The photographic plate size is 2.5 in. x 3.5 in.

3.1 Introduction.

The determination of the height and geographic position of the aurora borealis has usually been carried out by taking a pair of simultaneous photographs, one from each end of a measured base line, with tripod-mounted cameras. A camera frequently used for this work is that designed by Krogness which takes six photographs on one

9 cm. x 12 cm. plate by an arrangement that permits the objective lens to be set in six different positions relative to the plate. The directions to points on the aurora are then determined by reference to the recorded images of known stars. The position in space of any point on the aurora can then be computed if its image can be identified in both photographs. A more detailed account of this method has been given by Harang (1951, Ch.1).

This procedure has two disadvantages, viz. that considerable labour is involved in computing directions from star positions and it is often impossible to record satisfactory star images on the plate with an exposure duration short enough to produce a satisfactory image of the aurora; this is especially so with bright, moving auroras.

In order to avoid these difficulties, the ANARE uses a photo-theodolite (a theodolite in which the usual telescope is replaced by a camera) which enables direct reading of the azimuth and elevation of the centre of the photograph; the direction to any other point in the photograph is then determined from its coordinates in a grid reproduced on each photograph and the known distortion characteristics of the objective lens. At very low elevations correction for atmospheric refraction is necessary; this can be obtained from tables of refraction corrections or from the difference between measured and computed elevations of star images if these are identifiable in the photograph.

The photo-theodolite in use is bolted to a flange welded on the top of a 4 in. diameter steel pipe set in concrete. A reference mark on which a light can be fixed is set up at a distance of about 500 feet at zero elevation and at an azimuth which is a multiple of 2° from true north.

In designing the photo-theodolite the objective was to achieve mechanical reliability at low temperatures, sturdy construction in order that frequent adjustment would not be necessary, simplicity of operation and an accuracy of 1 minute in measurement of azimuth and elevation. Easy portability of the instrument was not considered necessary.

3.2 Description of the Photo-Theodolite.

A general view of the photo-theodolite is shown in Fig. 5; details of construction are illustrated in Figs, 6a, 6b and 6c. The main features of the instrument are described below:-

(a) The Azimuth and Elevation Bearings:- The azimuth bearing consists of two ground hardened steel annular bearing rings separated by a ball race of 120 steel balls spaced in a brass cage. Radial movement is

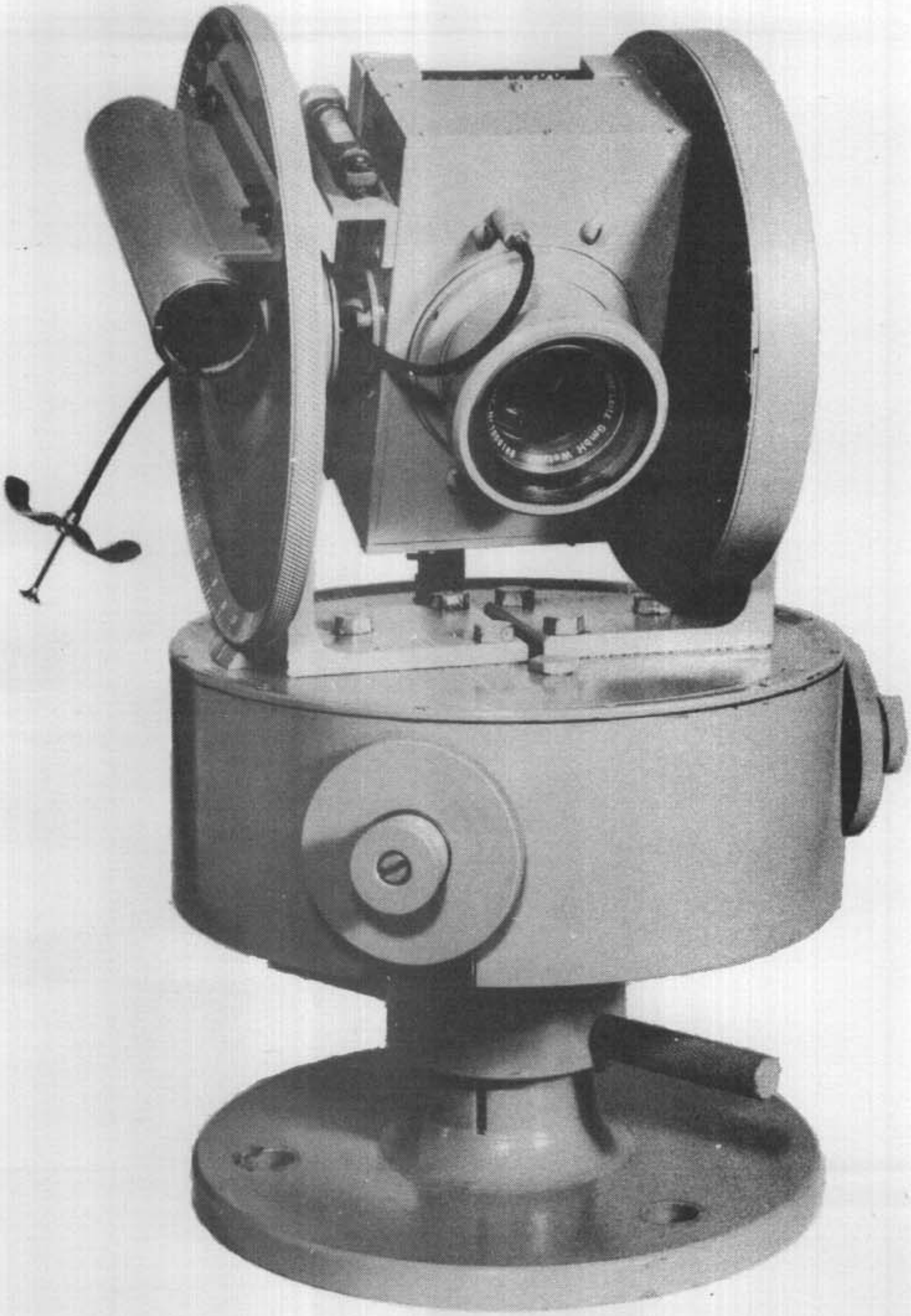


FIG. 5.

General view of the Photo- Theodolite

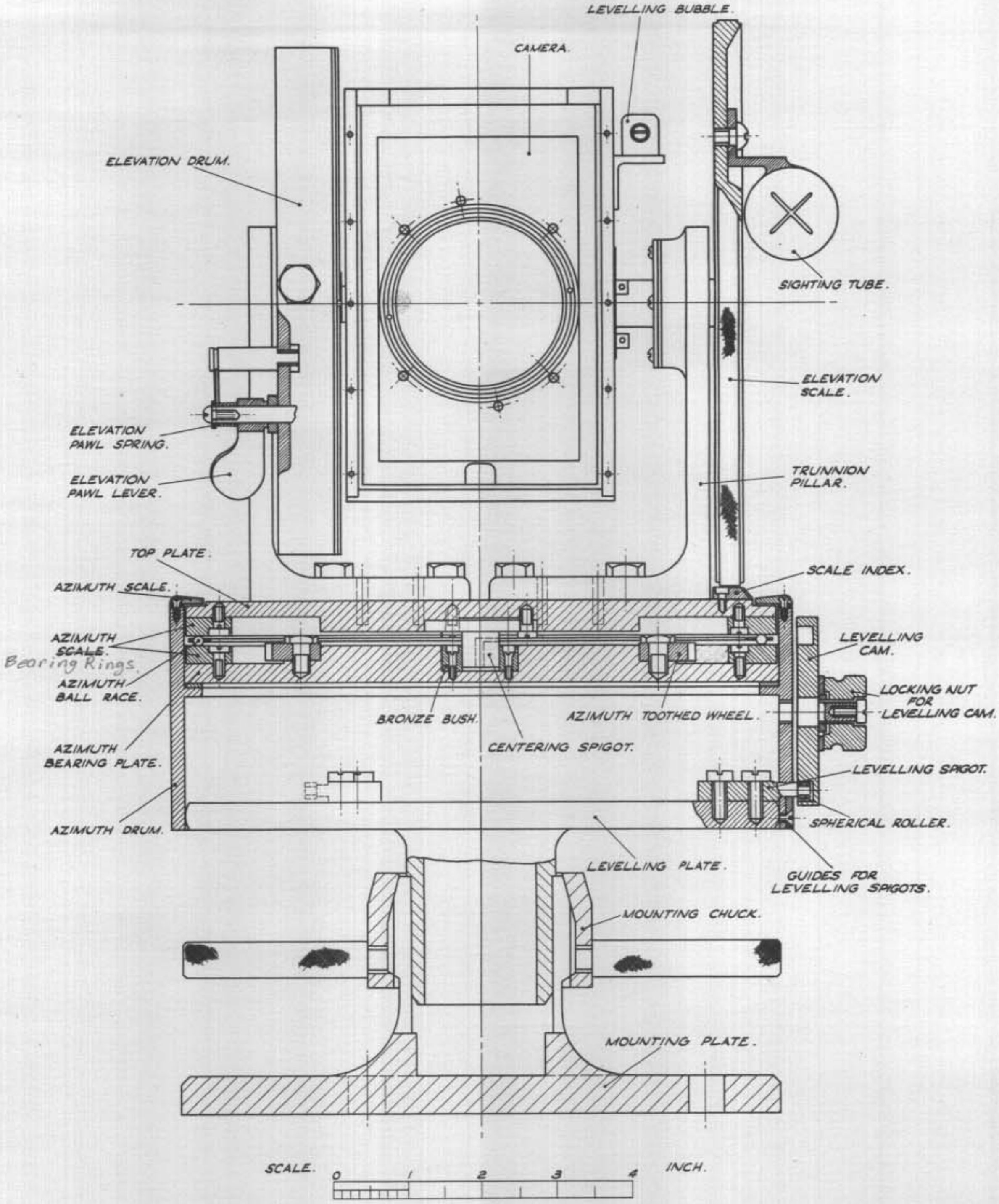


FIG. 6A.

ELEVATION OF THE PHOTO - THEODOLITE.

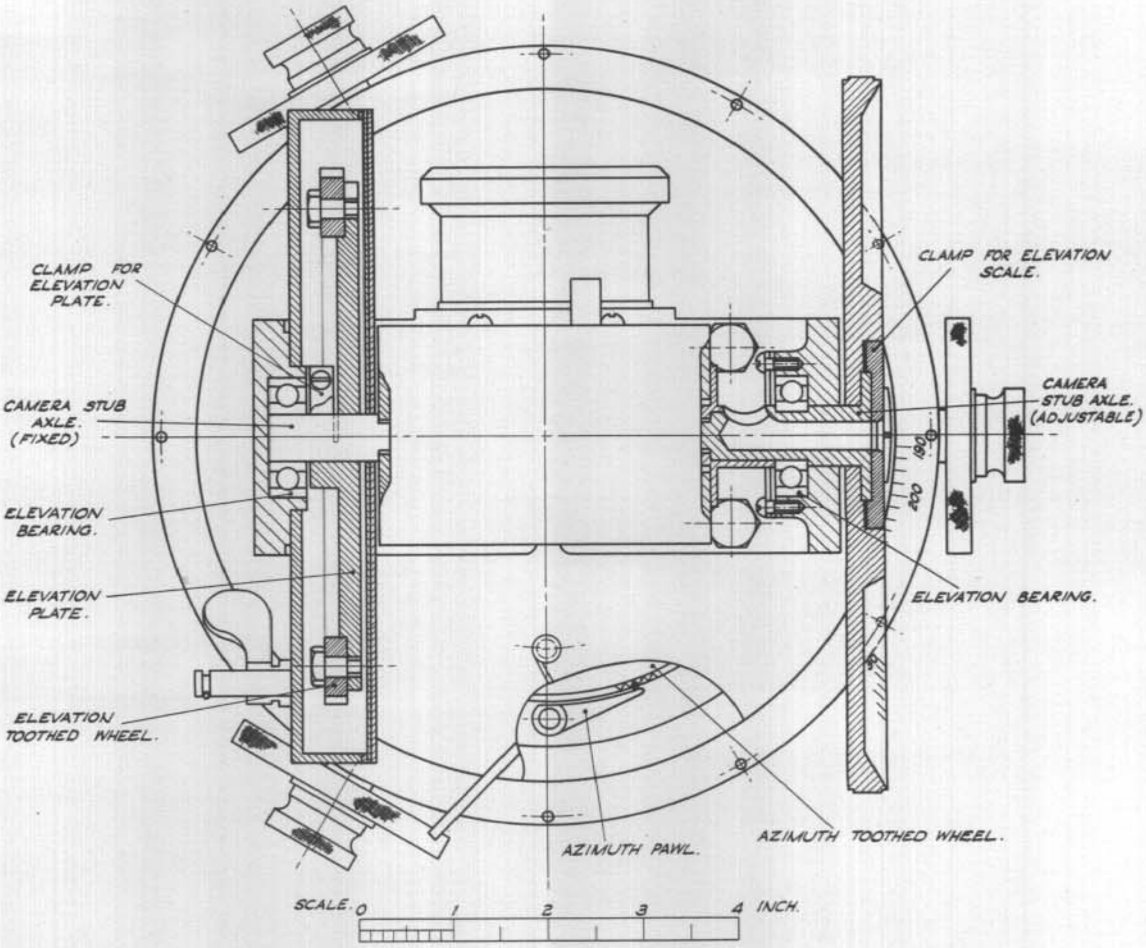


FIG. 6B.
PLAN VIEW OF THE PHOTO - THEODOLITE.

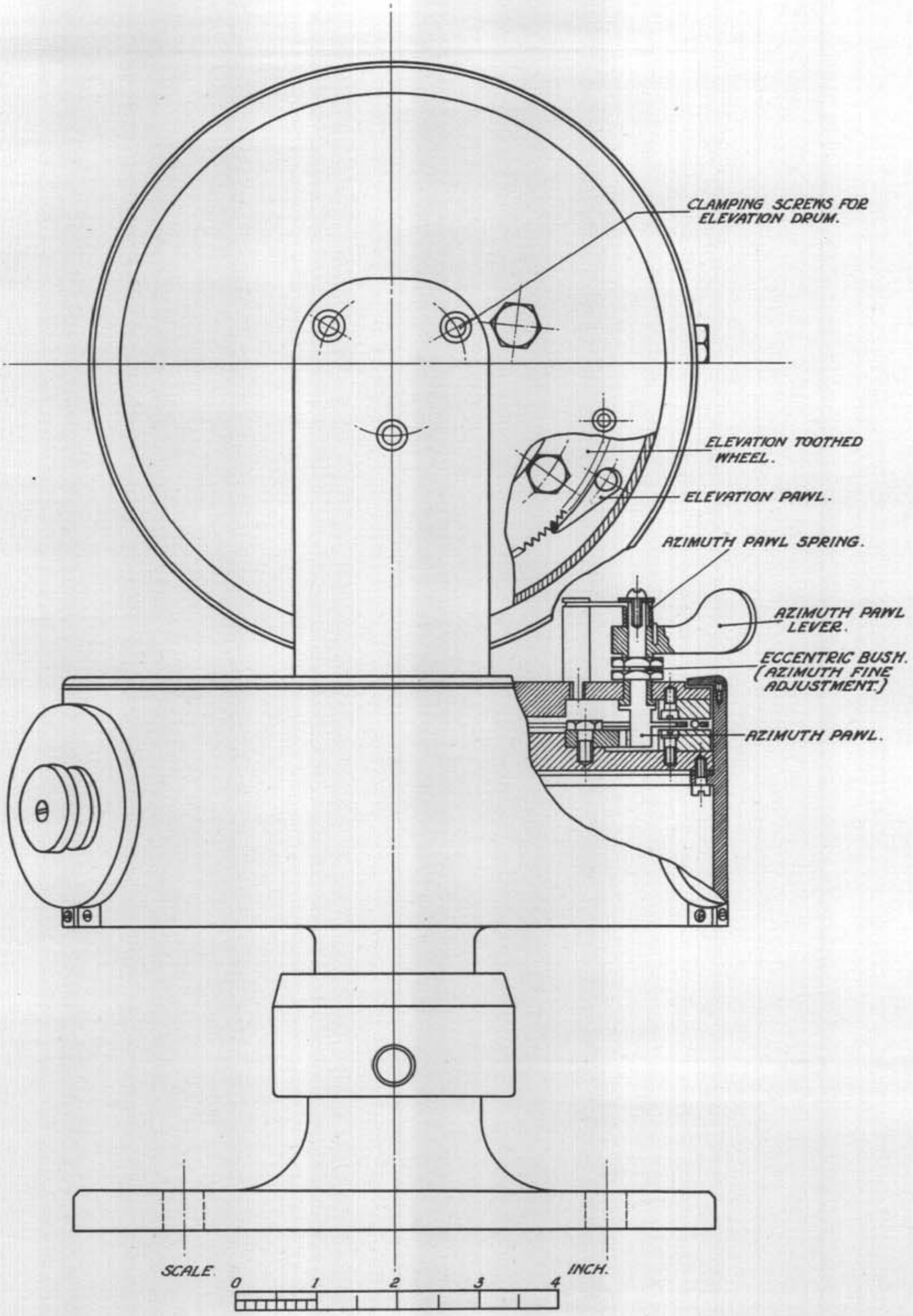


FIG. 6 C.

SIDE ELEVATION OF THE PHOTO-THEODOLITE.

prevented by a short 0.5 in. diameter steel centering spigot moving in a bronze bush which was pressed into its housing and held by two screws. The bore of the bronze bush is 0.0005 in. oversize to prevent seizing on the spigot at low temperatures. At normal temperatures this could introduce a maximum azimuth error due to radial movement of the spigot of 0.5 minutes.

This bearing is quite free even at a temperature of -50°C and cannot readily suffer damage or serious wear.

The elevation bearings are deep-groove single-row ball bearings which carry the short steel stub axles fixed to the camera body.

(b) The Levelling Device:- The instrument must be roughly levelled on its stand; fine adjustment is then obtained through three levelling cams using a 30 second per 2 mm. division bubble mounted on the side of the camera body.

Each levelling cam consists of a flat cylindrical drum, in one face of which is machined a spiral groove. The levelling cams rotate on horizontal spigots fixed to the azimuth drum. The levelling plate carries horizontal levelling spigots on the ends of which are small spherical rollers which roll in the spiral groove of the levelling cam as it is rotated. This introduces a vertical displacement between the two spigots which is proportional to the angle through which the levelling cam is rotated. A stop prevents rotation through more than one revolution which gives a vertical movement of 0.03 in.

The levelling spigots move in hardened steel guides fitted to slots in the azimuth drum. One side of these guides is adjustable to give about 0.0005 in. clearance on the levelling spigot to enable free vertical movement.

A locking nut holds the levelling cam to prevent movement after the adjustment is complete.

(c) Azimuth and Elevation Setting:- The direction of the camera axis is located by spring-loaded pawls which engage in toothed wheels, the teeth being spaced at 2° intervals. The azimuth and elevation are read at an index mark on external scales divided at 2° intervals. These scales are easily read with little illumination.

The azimuth and elevation toothed wheels are identical and those for three instruments were machined together from a high carbon, 2.5% nickel, chromium, molybdenum steel using the following procedure:-

1. Six annular rings were trepanned from 1/4 in. blank discs. Their surfaces were ground flat and parallel.

2. Each annulus was mounted in the chuck of a

dividing head with axis vertical and six equi-spaced holes were drilled.

3. The six annuli were bolted onto a face plate through four of these holes, dowel pins being fitted in the other two holes.

4. The internal surfaces of the annuli were bored and the outside surfaces turned concentrically.

5. The annuli with dowel pins in position were fitted to a mandrel and clamped concentrically on a rotary table fitted with optical scale reading direct to 1 min. of arc.

6. The rotary table was clamped on a milling machine with its axis vertical and in the plane of a 60° V cutter and the teeth machined, using a vertical feed, at 2° intervals around the periphery of the annuli.

The accuracy of the toothed wheels has been checked and all teeth are within 0.5 min. of their correct positions.

The azimuth toothed wheel is held by six screws onto a register machined on the azimuth bearing plate concentrically with the bore of the bronze bush.

The pawl, which has a cylindrical end to locate between two V shaped teeth of the azimuth toothed wheel, is carried on a vertical shaft which rotates eccentrically in a bush fitted in the top plate. Rotation of this bush permits fine adjustment of azimuth zero setting; its position is held after adjustment by a locking nut. Coarse adjustment is obtained by rotating the whole instrument in the mounting chuck which clamps the instrument to the mounting plate.

A torsion spring on the pawl shaft serves to keep the pawl normally engaged with the toothed wheel. A thumb lever pinned to the top end of the pawl shaft enables it to be disengaged.

The elevation toothed wheel is held by six screws onto a register machined on the elevation plate concentrically with a hole through the clamp which fixes the elevation plate onto the stub axle carrying the camera. Lead plates fixed to the elevation plate serve to balance the camera.

The elevation pawl is mounted on a horizontal shaft through the elevation drum. Fine adjustment of elevation zero is obtained by rotating the elevation drum after loosening the three screws which clamp it to the trunnion pillar.

(d) The Camera:- Details of the camera are shown in Figs. 7a, 7b and 7c. The camera body was fabricated from 10 gauge brass plate. The camera objective lens is a Leitz 'Summarit' of focal length 5 cm. and aperture f/1.5. The lens, with normal focussing mount removed, screws into a brass lens mount which in turn screws into

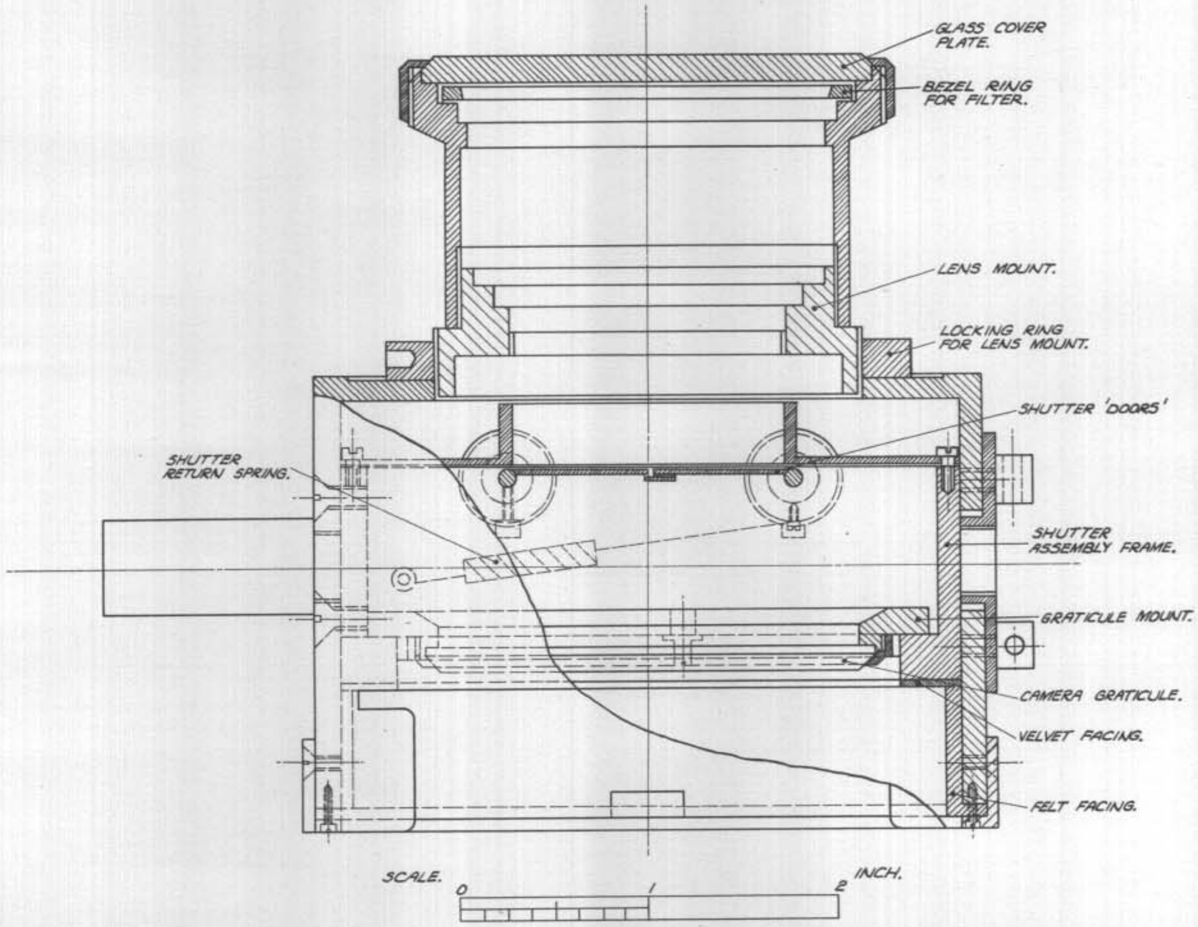


FIG. 7A.
ELEVATION OF THE CAMERA.

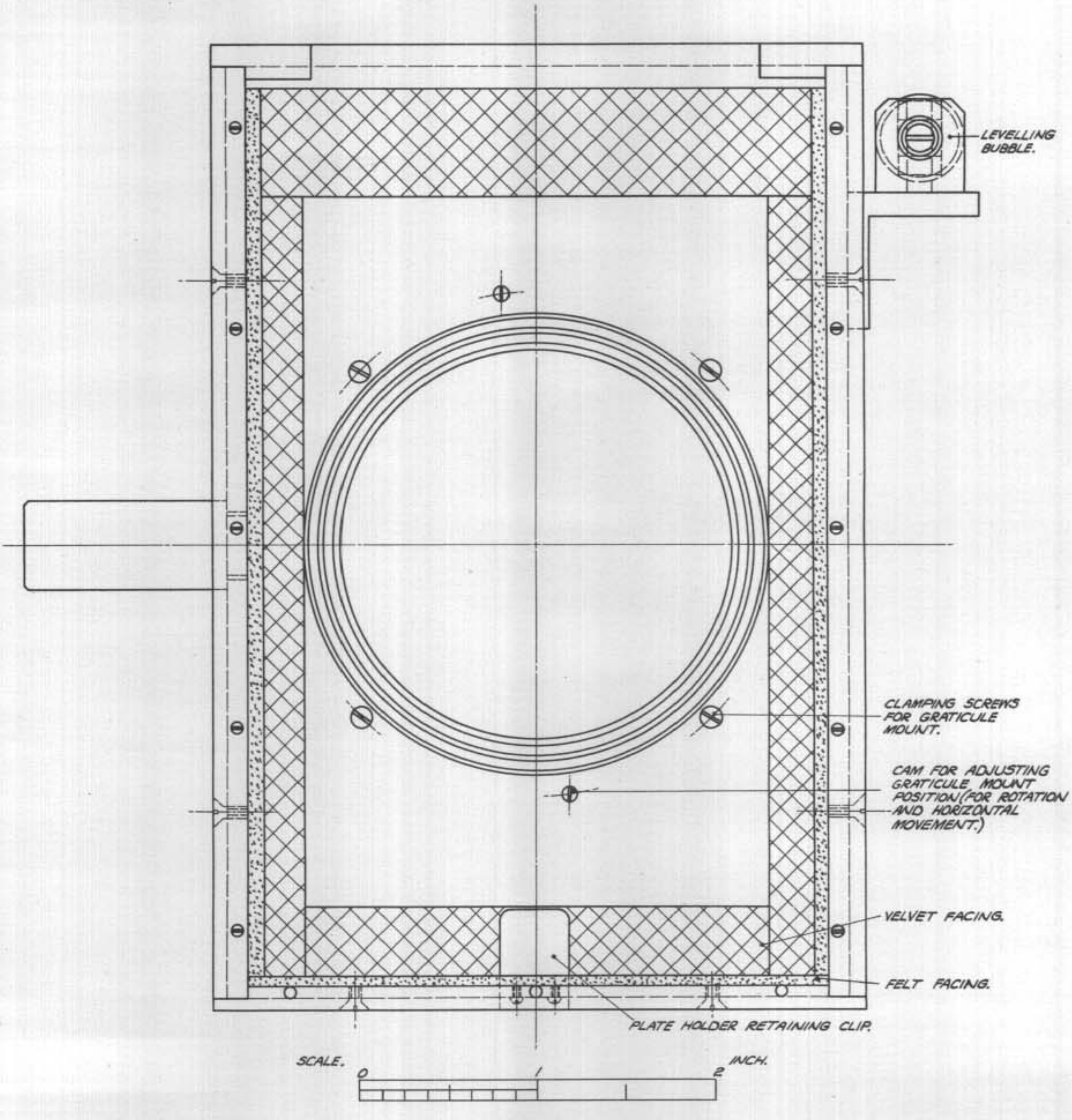


FIG. 7B.
PLAN VIEW OF THE CAMERA.

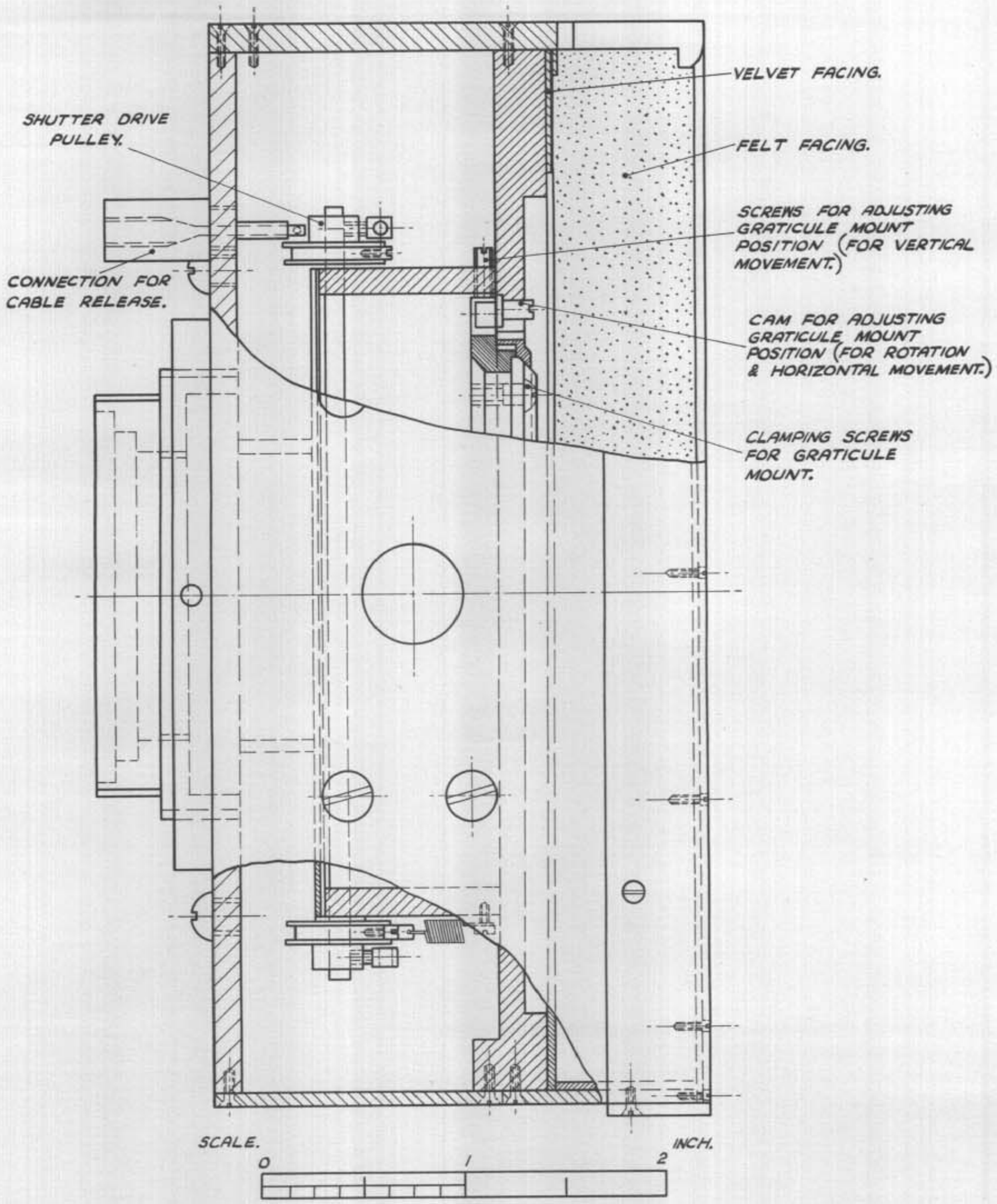


FIG. 7 C.

SIDE ELEVATION OF THE CAMERA.

the camera body - this provides the means of focussing. A large locking ring serves to fix its position.

A tube fitting over the lens and screwed onto the lens mount carries a flat glass cover plate to protect the lens from damage. This can be replaced by a silvered flat mirror to enable focussing and collimation of the camera. Provision is made to fit a 2 in. diameter interference filter in the tube behind the glass cover plate.

The camera is mounted between two steel stub axles one of which can be moved slightly forward or backward (perpendicular to the axis of the stub axle) to enable adjustment of the mechanical axis at right angles to the optic axis of the lens.

The camera shutter consists of 'double doors' between the lens and focal plane. These are mounted in a shutter assembly frame, which also carries the graticule and is held into the camera body by screws through the sides. This frame is fitted with a short tube which surrounds the part of the lens which projects into the camera body.

The shutter 'doors' close onto a velvet facing on the inside of the shutter assembly frame; they open through an angle of approximately 140°. The shafts carrying the shutter 'doors' project through the top and bottom of the shutter assembly frame. On the bottom ends of these shafts small drums held on by grub screws prevent end play in the shafts. The shutter return spring (which holds the shutter 'doors' normally closed) is fixed via a spring steel belt to one of these drums.

Shutter drive pulleys fixed to the top ends of the shutter 'door' shafts are connected by a figure-8 belt drive made from spring steel strip 1/16 in. wide x 0.003 in. thick. The shutter is opened by a silver chain fixed to the periphery operating around a drum on one of these pulleys. A short steel pin fixed to the other end of the chain is pushed in a guide by the plunger end of a cable release fixed into the front of the camera body. From this point the cable passes through a hole into the hollow stub axle supporting the camera and out through the centre of the elevation scale. The end of the cable release is fitted with finger stirrups to enable easy operation with gloved hands. In case of failure the cable release can be replaced by a short direct drive plunger.

The shutter has been found very reliable and capable of satisfactory performance at exposures down to 2/5 second. For shorter exposures (which are very rarely necessary), the opening and closing time is comparable with the duration of exposure of the centre of the plate.

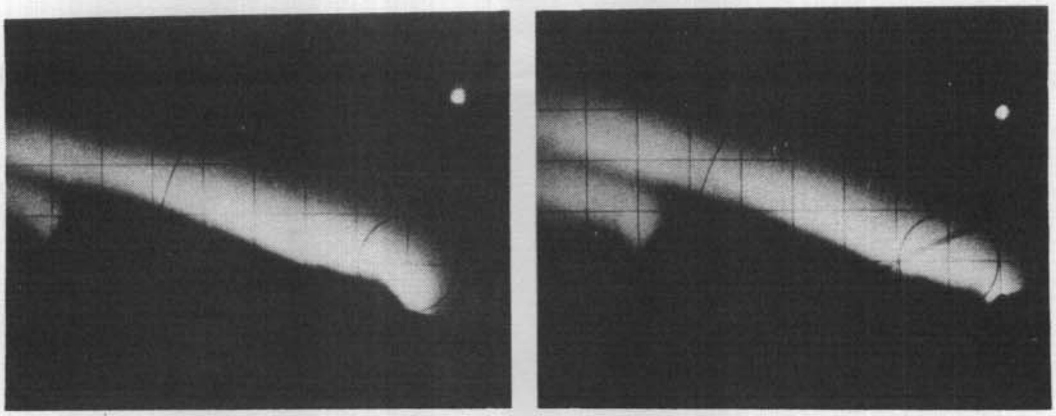
(e) <u>The Camera Graticule</u>:- The graticule is held by a bezel ring into a mount which is clamped by four screws to the shutter assembly frame which also forms the back of the camera. The holes in this frame through which the four screws pass are 'drawn' to enable adjustment of the graticule position.

The lens is adjusted to bring its focal plane coincident with the plane of the graticule which produces a shadow on the photographic emulsion (See Fig. 8) which is brought into contact with it by means of the special plate holder described below.

The form of the graticule is illustrated in Fig. 9. The lines which are filled black were photo-etched on glass blanks 1/8 in. thick, the surfaces having been worked flat to within 1 wavelength and parallel to within 10 seconds. (The front cover glass was made to the same specifications).

The graticule line spacings are 0.1 in. ±0.0005 in. the line thickness being 0.0005 in. The circles are merely to enable location of the centre of the graticule.

(f) <u>The Plate Holder</u>:- The plate holder (See



N.P. 101.

S.P. 101.

FIG. 8.

A pair of photographs of a 'homogeneous band' taken with the photo-theodolite NP 101 from the north end and SP 101 from the south end of a base line of approximately 20 miles at Macquarie Island. Azimuth of camera axes 256°, elevation 10°; exposure 10 sec. at 09h52m. G.M.T. on 25-9-54.

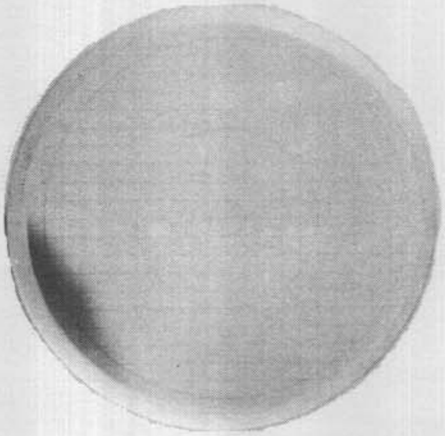


FIG. 9.

The Camera Graticule.

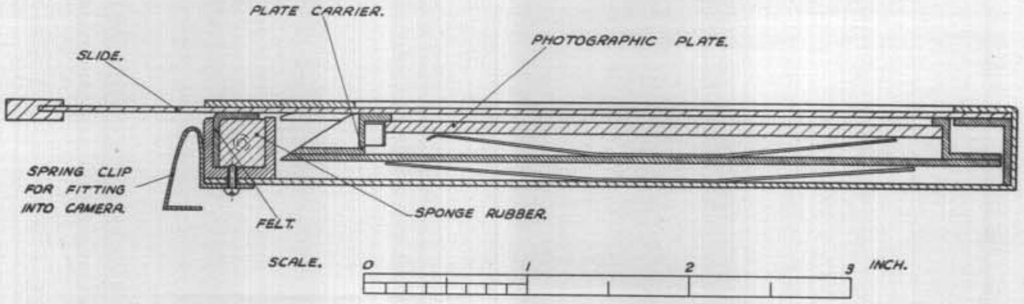


FIG. 10.

SECTION SHOWING SOME DETAILS OF PLATE HOLDER CONSTRUCTION.

Fig.10)) which clips into the back of the camera is designed so that on removal of the slide it brings the emulsion of the photographic plate into contact with the graticule surface without sliding motion which would damage both the emulsion and the graticule.

The photographic plate size is 2.5 in. x 3.5 in.

The plate fits into a plate carrier which is housed in the plate holder body under pressure from two leaf springs which force the plate carrier forward when the slide is pulled out. One end of the plate carrier is sloped in the form of a ramp which bears against the leading edge of the slide and so enables the plate carrier to be depressed into the plate holder body when the slide is inserted.

Twelve plate holders are supplied with each instrument.

(g) The Sighting Tube:- The sighting device consists of a tube carrying a lens in one end and cross slots in a disc in the focal plane of the lens at the other end. The tube is mounted on the side of the elevation circle with its axis parallel to the optic axis of the camera lens,

To sight, the instrument is turned to bring the image of the cross as seen through the sighting lens with the left eye into coincidence with a point on the aurora which is to be near the centre of the picture as seen with the right eye.

(h) <u>The Instrument Cover</u>:- The instrument when not in use is protected by a metal can which is clamped down by three clips to its bottom plate which is bolted between the mounting plate of the instrument and the flange top of the mounting post.

(i) <u>Lubrication</u>:- The azimuth bearing and the azimuth toothed wheel operate in oil which fills the space between the azimuth bearing plate and the top plate. The elevation bearings, elevation toothed wheel and levelling cams are greased. The bearings which carry the shutter 'door' shafts can be oiled as necessary through holes (normally closed with screws) in the front of the camera body.

The oil used is Mobil Aero Instrument Oil, a mineral oil with added corrosion inhibitor satisfying British Specification DTD 561. The grease is Mobil Grease Aero Lo-Hi, a lithium-base grease satisfying British Specification DTD 577. Both of these lubricants perform satisfactorily at temperatures down to -50°C.

3.3 <u>Adjustment of the Photo-Theodolite</u>.

The following procedure is devised to enable adjustment of the photo-theodolite in the field; it involves the use of a distant reference mark or light at zero elevation and azimuth $R^\circ = 2n^\circ$, (n being any integer). In the laboratory this reference mark can be replaced by a levelled collimator.

1. Set the elevation scale to read zero.

2. Call the levelling cams, A, B and C:-

(a) Rotate the camera in azimuth till the levelling bubble is parallel to A - B; centre the bubble by adjusting A and B.

(b) Rotate the camera through 180° in azimuth, adjust the bubble mount to halve the error in bubble centering, then centre the bubble by adjusting A and B.

(c) Rotate the camera 90° in azimuth and centre the bubble using C.

(d) Repeat (a), (b), and (c) till no further adjustments are required. The 'vertical' axis of the instrument will now be vertical.

3. Replace the front cover-glass with the back-silvered mirror (this is made from a blank glass worked to the same specifications as the graticule and cover glass) and illuminate the graticule from the side if necessary.

(a) Screw the lens in or out to bring the image of the graticule into the plane of the graticule. (There will then be no parallax).

(b) Move the graticule till it is coincident with its image.

4. With scales reading elevation 0° and azimuth R° bring the image of the reference mark onto the centre intersection of the graticule by :-

(a) Moving the instrument in the mounting chuck (coarse adjustment for azimuth) then turning the eccentric bush carrying the azimuth pawl shaft (fine adjustment for azimuth)

(b) Rotating the elevation drum (fine adjustment of elevation).

5. Centre the bubble by adjustment of the bubble mount; repeat 2 and 4 if necessary.

6. Repeat 5 until no further adjustment is required.

7. Rotate the graticule till the image of the reference mark lies on the centre vertical line of the graticule for all elevation settings.

8. Repeat 2 to 7 till no further adjustment is required.

9. (a) Transit the camera (i.e. turn through 180° in azimuth and in elevation). The image of the reference mark should then still be on the centre horizontal line of the graticule but will be displaced

from the centre vertical line if the angle between the optic axis of the camera lens and the trunnion axis (horizontal mechanical axis) is not 90°.

(b) Halve this displacement by adjusting the movable stub axle.

(c) Repeat 4(a) (fine adjustment only).

(d) Repeat (a), (b) and (c) till no further adjustment is required.

10. Repeat 1 to 9 till no further adjustment is required.

For the purpose of routine checking, each night the instrument is used, test photographs are taken of a light on the reference mark as follows:- Direct the camera toward the reference light (elevation 0°, azimuth R°) and expose; keep the azimuth constant and expose for an elevation of say +16° and -16°; then with elevation 0° expose for azimuths 16° each side of the reference light. Transit the camera and repeat this procedure with another test photograph. The images of the reference light should all fall on the centre vertical and horizontal lines of the graticule.

Determination of the lens distortion characteristics can be made in the field by setting up a light, at zero elevation and distant at least 2000 ft., and taking a series of photographs (on the one plate) at 2° intervals in azimuth setting. A graph of angular distance from the optic axis against linear distance of the image of the light from the centre of the graticule (measured in units of graticule line spacing) can then be drawn.

3.4 Conclusions.

Two photo-theodolites of the type described in this report have been in operation at Macquarie Island for more than one year and have proved to be reliable and simple to operate under the extremely adverse weather conditions experienced. Readjustment of the instruments was required only once during this period.

With the photo-theodolite described the azimuth and elevation of a well defined point (e.g. a star image of moderate density on the negative) can be obtained to within 1 or 2 minutes. This limit is determined by the accuracy of construction of the instrument and by the resolution of the photographic plate used. However, on account of the lack of sharpness which usually characterizes features of the aurora, it is only rarely possible to identify corresponding points on the two pictures of an aurora to this order of accuracy.

ACKNOWLEDGEMENTS

The writers wish to thank Mr. D. Grant who carried out the initial trials with the 'Open Sights' Theodolite and the Superintendent, Defence Standards Laboratories, Department of Supply, who provided workshop facilities for the construction of the photo-theodolites. Messrs. R. H. Wilkinson and K. D. Short installed and used the instruments at Macquarie Island and advised on their performance.

REFERENCES

HARANG, L., 1951. The Aurorae.

LA COUR, D., 1932. Supplement to the Atlas of Auroral Forms.