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# TRANSLATION

HIGH-PRECISION OPTICAL THEODOLITES

by

B. S. Grishin

## FOREIGN TECHNOLOGY DIVISION

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# UNEDITED ROUGH DRAFT TRANSLATION

HIGH-PRECISION OPTICAL THEODOLITES

BY: B. S. Grishin

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# VYSOKOTOCHNYYE OPTICHESKIYE TEODOLITY

Izdatel'stvo Geodezicheskoy Literatury

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# Preface

Modern geodesic instrument construction covers a wide range of subjects associated with the design and development of manufacturing processes, manufacture and assembly, and also with the development of methods of adjustment and inspection procedures.

Amongst existing designs at precision levels, types NB-2 and Ni-004 satisfy modern requirements whilst conventional precision theodolites and universal instruments (types TT-2/6 and AU 2/10) require modernisation. New types of precision optical theodolites are now being developed.

The most widely used of the existing designs is theodolite type OT-02, which is light in weight, small in size, hermetically sealed and at the same time of high accuracy. It is suitable for use in forests, mountains and inaccessible regions, for topographical geodesic work and in many other branches of the national economy.

In recent years a considerable number of optical theodolites type OT-02 have been supplied for topographical geodesic work. These instruments are also used by other organisations, and so it was considered necessary to revise the book High-Precision Optical Theodolites, first published in 1954. It is a practical handbook on the assembly and adjustment of these instruments.

Experience of the manufacture of the precision optical theodolite type OT-02 indicates that the corresponding manufacturing instructions must be strictly observed in making the components and in assembling the instrument so that it meets the stringent technical requirements which apply to it.

This book describes the fundamentals of the assembly, dismantling and adjustment of precision optical theodolites types



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CT-02 and ThB. It describes the manufacture of parts of the axial system and the study of aberrations in the telescope optical system. Rules for the care of high-precision optical theodolites are given.

The following additions have been made in the second edition of the book:

(a) Chapter 3 describes the testing and investigation of the optical micrometer and also investigation of the optical theodolite dials;

(b) Chapters 4 and 7 give the theoretical fundamentals of the individual processes for adjusting the optical systems of types OT-02 and ThB theodolites.

The author hopes that the book can serve as a textbook not only for specialists in geodesic instrument manufacture, but also for students in geodesic colleges, taking courses in applied optics and geodesic instrumentation.

## Introduction

Theodolites types OT-02 and ThB have considerable advantages over the triangulation theodolites and universal instruments types TT 2"/6" and AU 2"/10", namely: they are small, hermetically sealed, comparatively light and more convenient for observations, which speeds up the work and makes them more suitable for use in inaccessible, mountainous and remote districts.

Optical theodolite type OT-02, manufactured by the Aerogeoinstrument works is used in high-class triangulation, and it can also be used for class 3 astronomical observation. Recently, it has also been used in machine-tool manufacture to determine the error in the tooth-pitch of precision gear wheels and for other angular measurements.

In order to work with these precision optical theodolites it is necessary to understand their construction, and the function and arrangement of the individual components and assemblies, the optical systems and the path of light through them, and also the inspection and adjustment of the assemblies and of the instrument as a whole.

Precision optical theodolites contain about 70 optical parts, which is just about 10% of all the parts of the instrument. Therefore the quality of the instrument depends not only on the optics but also on the quality of manufacture and the assembly of the mechanical parts.

In instruments such as high-precision optical theodolites adjustment is a complicated process which includes the fitting of the optical and mechanical parts, and inspecting assemblies and the instrument as a whole in accordance with the drawings and technical requirements.

PART 1

# OPTICAL THEODOLITE TYPE OT-02

## Chapter 1

## GENERAL INFORMATION

In optical theodolites the horizontal and the vertical dials are made of optical glass and the optical systems of the horizontal and vertical dial microscopes transmit images of diametrically opposite dial graduation lines to the field of the reading microscope. The instrument has a single optical micrometer in place of several microscope-micrometers.

Optical theodolite type OT-02 is a precision geodesic instrument. Its special feature is that the images of the graduation lines of the horizontal and vertical dials are transmitted through the optical systems of the objectives of the horizontal and vertical dial microscopes to the single field of vision of the reading microscope, which has its eyepiece alongside that of the telescope. The readings are made on a single optical micrometer of which the seconds disc is calibrated at 0.2" per division. The telescope is of the astronomical type, straight, central, and with internal focussing. The instrument can operate normally over a temperature range of -25 to +50°C. Electric lighting is provided.

The instrument case is 233 mm in diameter and 420 mm high. Without the centering plate the instrument weighs 10.8 kg , the instrument complete with case weighs 14.8 kg , the tripod weighs 8 kg and the centering plate 4.18 kg.

The theodolite is provided with the following set of accessories:

Illuminating mirror; 2

Electric lamp; 2

Eyepiece cap with light filter of glass TS-3; 1

Interchangeable eyepieces to give telescope magnification of 40 x and 24 x; 2

Electrical plug-socket; 1

Cover for telescope objective; 1

Centering plate with centering device; 1

Tripod; 1

Metal case; 1

Attachment for carrying instrument; 1

Handle; 1

Plumb line with cord and board; 1

Spanner for tripod; 1

Tommy-bar for stand screw; 1

Screwdriver, watchmaker's; 1

Screwdriver with wooden handle; 1

Straight and bent pins; 2

Adjustable spanner; 1

Brush for cleaning optical parts; 1

Flannel cloth 200 x 200 mm; 1

Bottle of instrument lubricant; 1

Electric lamp; 10

Instrument cover of hard thin cloth; 1

Canvas bag for centering plate and accessories; 1

Canvas cover for tripod head; 1

## 1. The theodolite

Optical theodolite type OT-02 consists of three main interconnected parts: the lower, middle and upper (the telescope and horizontal axis). The middle part of the theodolite is attached to the upper part by screws, and to the lower part by a screw thread in the stand and on the mounting of the dial alidade prisms.

A general view of optical theodolite type OT-02 on its centering plate A is given in Fig.1. The base plate 1 serves as a base for the levelling screws. It is secured to the tripod by a fixing screw and to the centering plate by a special screw.

<u>Lower part of the theodolite</u>

The principal component of the lower part is the carrier 4 (Fig.1). The levelling screws 2 serve to adjust the vertical axis of the instrument over the plummet. The travel of the levelling screws is controlled by the screws 3. The mounting 7 of the condenser and illuminating prism for the horizontal dial and also a plug-socket are attached to the base of the carrier. Attached to the carrier opposite the lighting prism is a mounting for the interchangeable lighting systems (mirror and electrical).

Inside the carrier is the dial bush and horizontal dial, the mounting of the alidade prisms and the mounting for the components of the horizontal dial microscope objective. The horizontal dial is attached by four special clamps to the dial bush, which can rotate.

Under the protective cover 5 is a knob which is secured to the same spindle as a gear which meshes with the gear on the dial bush, so that the dial rotates when the knob is turned.

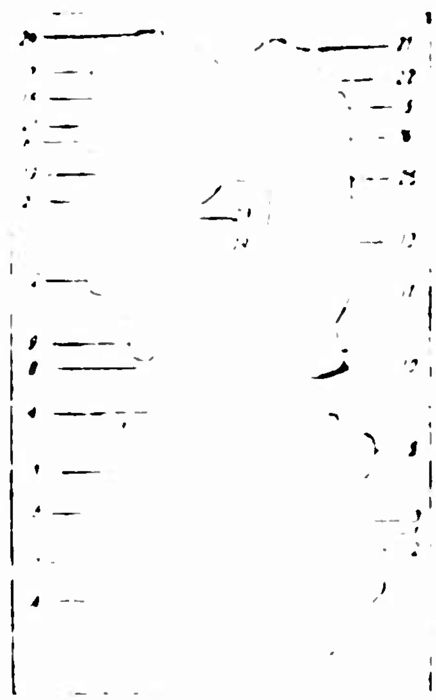

Fig. 1. Optical theodolite type OT-02

1 - base plate; 2 - levelling screws; 3 - adjusting screws; 4 - carrier; 5 - protective cover for knob of pinion which sets horizontal dial; 6 - illumination mirror; 7 - mounting of illuminating prism of horizontal dial; 8 - sliding contact; 9 - locking screw for clamp of horizontal dial alidade; 10 - adjusting screw for horizontal dial alidade; 11 - telescope sighting adjustment screw; 12 - level setting screw for the vertical dial; 13 - selector knob; 14 - level for horizontal dial alidade; 15 - optical micrometer knob; 16 - micrometer bearing; 17 - level for vertical dial alidade; 18 - vertical turntable housing; 19 - telescope focussing ring; 20 - eyepiece focussing ring; 21 - telescope clamping screw; 22 - graticule illuminating mirror knob; 23 - objective lens of vertical dial microscope; 24 - rotating level prism; 25 - reading microscope; 26 - level adjusting screw for vertical turntable; 4 - centering plate.

The vertical axis of the instrument is secured to the stand. A contact ring and clamping sleeve are fixed in the upper part of the carrier. The clamping ring carries the alidade clamp of the horizontal dial with adjusting screws 10 and locking screws 9.

Middle part of theodolite

The stand, with its two uprights, is the principal component of the middle part of the theodolite. The lower part of it carries the following: the level for the horizontal dial 14, the swivelling prism (with mounting) of the objective system of the horizontal dial microscope; on the left (with circle-left, or CL) the swivelling prism of the objective system of the vertical dial microscope in its mounting, the objective lens of the vertical dial microscope 23 in its mounting, the level setting screw for the vertical dial 12; to the right (with circle-right or CR) the telescope sighting adjustment screw 11, the selector prism in its mounting with the knob 13 and cover glass. The image of the graduations of the horizontal or of the vertical dial is selected by turning the knob 13.

Upper part of the theodolite (telescope with horizontal axis)

This is the most complicated part of the instrument in both manufacture and assembly. The composite horizontal axis of the instrument is cylindrical and hollow. The telescope turns cylindrical bearings. The principal component and joining link of the upper part of the theodolite is the telescope socket. The telescope and the reading microscope 25 are attached to the telescope socket which also holds the clamp and knob of the graticule lighting mirror 22.

The bearings are screwed to the instrument stand. The right-hand bearing 16 contains an optical micrometer with knob 15; the left-hand one contains the mounting for the vertical dial alidade prisms to which is secured the clamp of the vertical dial alidade level. The vertical dial alidade is turned by the adjusting screw 12.

The principle of combining the images of the two opposite ends of the level bubble is used to adjust the bubble to the central position. The coinciding ends of the bubble are observed through a rotating level prism 24.

The position of the zenith is altered by the telescope sighting adjustment screw 11, the level setting screw for the vertical dial 12 and the level adjusting screw 26

The vertical dial, which is screwed to the telescope socket is attached to the frame of the vertical turntable 18.

The image of the telescope graticule is focussed by turning the focussing ring of the eyepiece 20 and the main object is brought into focus by turning the telescope focussing ring 19. The collimation error is corrected by adjusting the graticule position with three screws. The telescope graticule lighting is adjusted by turning the lighting mirror knob 22.

For astronomical observations the instrument is provided with a dark glass filter which fits onto the telescope eyepiece.

## Levels

Theodolite OT-02 has two levels. The level for the horizontal dial alidade is mounted in the theodolite base and serves to bring the centre-line of the instrument over the plummet position. Levelling is adjusted by a screw on the side of the vertical dial. The calibration of the level is 6 - [illegible]" per 2 mm. The level for the vertical dial alidade is connected to the dial, its calibration is 10 - 12" per 2 mm.

## Reading the dials

The field of vision of the reading microscope is illustrated in Fig.2. The horizontal dial is read as follows; the micrometer knob is turned until the images of the dial graduations coincide accurately, and then the degrees and minutes (14°20') are read on the upper scale; the reading 20.07 is obtained on the (lower) "seconds" scale which, being multiplied by 2, gives 40".14. The complete reading is therefore 14°20'40".14. For greater accuracy the dial is adjusted and read twice and the sum of the two readings on the seconds scale gives the final result.

Example

| | |
|---|---|
| Reading on upper scale | 156°38' |
| First reading on seconds scale | 40.27 |
| Second reading on seconds scale | 40.21 |
| Total reading | 156°39'20".48 |

The method of taking readings on the vertical dial is similar to that described (but it should be borne in mind that diametrically opposite graduation marks on the vertical dial are numbered the same.

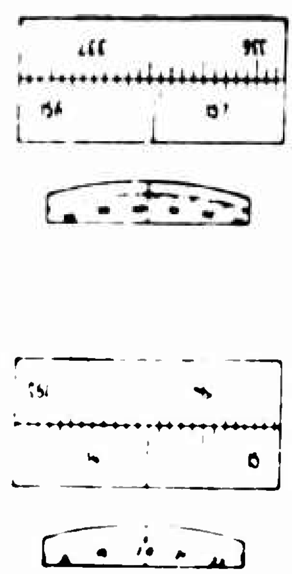

Fig. 2. Field of vision of reading microscope of theodolite type OT-02

The angle of slope is obtained as the differerce between readings when approaching from circle left (CL) and from circle right (CR) and not the half-difference as in ordinary instruments, i.e.

$$\alpha = CL - CR$$

and the zenith distances are calculated by the formula

$$M_z = CR + \alpha - 180^\circ$$

The reason for this is as follows: the intervals between graduations on the vertical and horizontal dials are divided into fifteen equal parts. The interval between adjacent graduations of the vertical dial is 8', which is double the interval on the horizontal dial. Therefore the whole-integer part of the reading on the vertical dial is divided by two in advance, i.e. 0,1,2... is written in place of 0,2,4... Consequently, the difference between readings taken when the telescope axis is aimed at the upper and lower points is half the actual angle, and the angle of slope is the difference between the readings. This is a special feature of theodolite OT-02.

## 2. Optical system

The optical system of the theodolite (Fig.3) consists of the optical systems of: (a) the telescope (b) the objective of the horizontal dial microscope (c) the objective of the vertical dial microscope (d) the micrometer (e) the reading microscope (f) the horizontal and vertical dials.

The telescope optical system consists of an objective, the graticule, and one of three interchargeable eyepieces.

The principal characteristics of the telescope are as follows:

| | |
|---|---|
| Tube length | 265 mm |
| Magnification | 24 x 30 x 40 x |
| Angle of vision | $1^{\circ}40'$, $1^{\circ}20'$ and $1^{\circ}$ |
| Eyepiece lens aperture | 2.5mm, 2.0mm and 1.5mm |
| Equivalent focal length of objective | 350 mm |
| Free aperture of objective | 60 mm |
| Resolving power of objective | 2".4 |
| Angular distance of graticule bisector | 35" |
| Focussing range | from 5m to infinity. |

The telescope objective consists of the objective proper (three lenses 35, 36 and 37 in Fig.3) and a double-lens focussing component 38. The graticule consists of two plane-parallel plates 39 and 40 cemented together, one of which carries the hair-lines and the other the diaphragm. The interchangeable eyepieces 41 are symmetrical and contain four lenses, their focal lengths are 14.6mm, 11.7 mm and 8.6 mm.

The optical system of the horizontal dial microscope objective consists of the horizontal dial lighting system, the alidade prisms 19, 21, an objective with four-times magnification 22,23, and the adjustable prism 24.

The horizontal dial lighting system includes: a prism 17, a condenser 18, alidade prisms 19,21 for each side of the dial, which are constructed so that the dial graduations can be lit and their images can be transmitted through objectives 22, 23 of the horizontal dial microscope. The horizontal and vertical dials are lit either by mirrors 6 which can be rotated about vertical and horizontal axes (Fig.1) or by electric lighting. The seconds disc of the optical micrometer is lighted together with the dials.

Fig. 3. Diagram of optical system of theodolite type [illegible]

The optical system of the vertical dial microscope objective consists of the vertical dial lighting system, the alidade prisms 8,10, an objective with three-times magnification 11,13, an adjustable prism 12, a cover glass 14, and a selector prism 15.

The vertical dial lighting system includes the prisms 5,6, a condenser 7 and alidade prisms 8,10, which, like the horizontal dial optical system, is constructed so that the dial graduations can be lit and their images can be transmitted through the first component of the vertical dial microscope objective 11. Prisms 1 and 2, which transmit light to a metal mirror which lights the graticule, are assembled together with the vertical dial lighting system.

The micrometer optical system is constructed in such a way that the images of the graduations of the horizontal and vertical dials and those of the graduations of the seconds disc and of the micrometer index appear on a single plane in which they are observed through the reading microscope (30, 31, 32, Fig.3).

The micrometer optical system consists of plane-parallel plates 25, a separating unit 26,27, a prism 28 which transmits the images of the dial graduations, the seconds disc 33, and the illuminating prism 34.

The reading microscope consists of the collecting lens 29, the reading microscope prism 30, the objective 31, and the eyepiece 32. The reading microscope is common to the optical systems of the microscope objectives of the horizontal and vertical dials, because both objectives give images in the plane of the separating unit 26, 27. The magnification of the reading microscope is 9.3 x and the overall magnification of the microscope for the horizontal dial is 37 x and for the vertical dial 28 x . The field of vision of the reading microscope is 8 mm x 3.8 mm which corresponds to 1°40' on the horizontal dial and 3°20' on the vertical dial. The distance from the microscope objective lens to the horizontal dial is 25.5 mm and to the vertical dial 25.0 mm. The diameter of the objective lens is 1.7 mm for the horizontal dial and 1.6 mm for the vertical.

The horizontal and vertical dials of theodolite type OT-02 are made of optical glass grade BK-10, and very strict requirements apply to them. The light beam which is reflected from the dial calibrations passes through the dials whose faces must, therefore, be parallel. The angle between the faces of the horizontal dial must not exceed 2 seconds and the quality of its surfaces is characterized by the values $\Delta N = 0.3$, $N = 1$, where $\Delta N$ is the tolerated deviation of the surface from that of a sphere or plane (local error) and $N$ is the tolerated deviation of the radius of the surface of the part from the radius of the test glass or tolerated sphericity of the plane surface expressed as the number of interference rings. The surface finish of the diameters on which the graduations and numbers are marked is of Class 1.

The dial graduations are made with a precision circular dividing machine. Before calibration the glass is coated with wax, the machine cutter pierces the wax to the glass, which is then etched. The diameter of the circle on which the graduations are made, measured to the lower end of the calibrations, is 135 mm for the horizontal dial and 90 mm for the vertical; the smallest divisions of the dials are: horizontal 4' and vertical 8'; the thickness of the dial graduations is horizontal 6 - 7 microns and vertical 7 - 8 microns.

The dial surfaces on which the graduations are marked are silvered to improve reflection and are provided with a protective coating. The total error of diameter of the horizontal dial is not greater than ± 1.5", and of the vertical dial, not greater than ± 2.5".

Seconds disc

The seconds disc is made of optical glass and is 22 mm in diameter and 2 mm thick. The diameter of the circle on which the graduations are made is 20 mm, measured to the inner ends of the graduations. In the disc there is a hole 8 mm diameter for the cam shaft. Graduations are marked on the arc of the disc over an angle of 350°, this angle is divided into 600 parts, every tenth division of which is numbered from 1 to 60. In addition, there are four lines marked on both sides of the working part of the disc. The width of the lines on the seconds disc is 0.01 ± 0.002 mm.

<u>Microscopes and path of light</u>

Consider first the path of the light in the horizontal dial microscope (Fig.3). Light from the electric lamp, or light reflected from the mirror, falls on the prism 17, passes through the condenser 18, and on to the prism 19, and then through prism 21 to the diametrically opposite part of the dial and illuminates the graduations of the horizontal dial 20.

The path of light in the alidade prisms is shown in Fig.4. Light from the illuminated images of the opposite parts of the dial passes through the alidade prisms 21 (Fig.3) to the first component 22 of the objective and then to the second component 23 and further to the swivelling prism 24 and to the optical micrometer (meanwhile the selector prism 15 is not in use).

In the optical micrometer the light passes through the plane-parallel plates 25 to the separating unit 26,27, which separates by a fine line the opposite fields of the dial graduation images, here part of the light passes through the illuminating prism 34 of the seconds disc.

The collecting lens of the reading microscope 29 receives light from diametrically opposite graduations of the dial through prism 28 and light from the graduation images of the seconds disc.

After passing through the collector lens 29 the light passes through the prism of the reading microscope 30, the objective 31, and the reading microscope eyepiece 32.

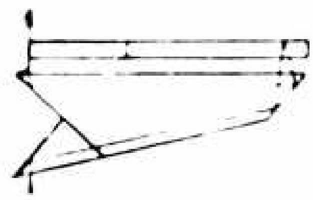

Fig. 4. Path of light in the alidade prism

The path of light in the vertical dial microscope is as follows (Fig.5): light from the electric lamp, or light reflected from the mirror, reaches the prism 5 and thence passes through the prism 6 and condenser 7 to the prism 8 and through the alidade prism 10 to the vertical dial 9. Thus, diametrically opposite graduations of the vertical dial are lit.

Further, light from the reflected images of diametrically opposite parts of the vertical dial passes through the alidade prisms 10 and reaches the first component 11 of the microscope objective, then passes through the swivelling prism 12 to the second component 13 and through the cover glass 14 to the selector prism 15. Passing through the selector prism 15 the light from diametrically opposite graduations of the vertical dial reaches the optical micrometer. The path of the light in the optical micrometer and in the reading microscope has been described above.

### 3. System of axes

The horizontal axis system of the instrument (Fig.5) includes the following parts: the bearing for the vertical turntable 29, the vertical turntable housing 18, the telescope socket 28 and the micrometer bearing 16.

The vertical turntable housing 18 (Fig.5) and the telescope 28 are connected by internal cylindrical surfaces; at one end they are in contact with the cylindrical bearing surface of the vertical turntable 29 and at the other with the cylindrical bearing surface of the micrometer 16.

The cylindrical surfaces of the mounting of the vertical-dial alidade prisms run in the bearing of the vertical turntable, and in the assembled system of the horizontal axis the alidade part of the mounting lies inside the vertical turntable housing.

The vertical axis of the instrument (Fig.6) includes the following components: the vertical axis 4, the vertical shaft main bearing (tribrach) 5 and the dial bush 6. The dial is mounted separately from the alidade axis, the dial runs in the dial bush 6, the alidade axis is the vertical shaft 4 and the vertical shaft main bearing 5 is located between them.

Mountings 1 and 2 of the objective components of the horizontal dial microscope (Fig.6) are located in the mounting of the dial alidade prisms 3 in which they are secured by locking screws after adjustment. The mounting of the dial alidade prisms is inside the vertical axis and is screwed to the instrument stand by a thread cut on its cylindrical part.

The vertical axis is self-adjusting, and cylindrical with a ball-thrust bearing on the conical part of the vertical shaft main bearing which is fixed to the stand by four screws. The vertical shaft main bearing is attached to the carrier by screws in half-rings. The half-rings run in the annular slot of the dial bush and, therefore, they are held above the horizontal dial alidade prism mounting.

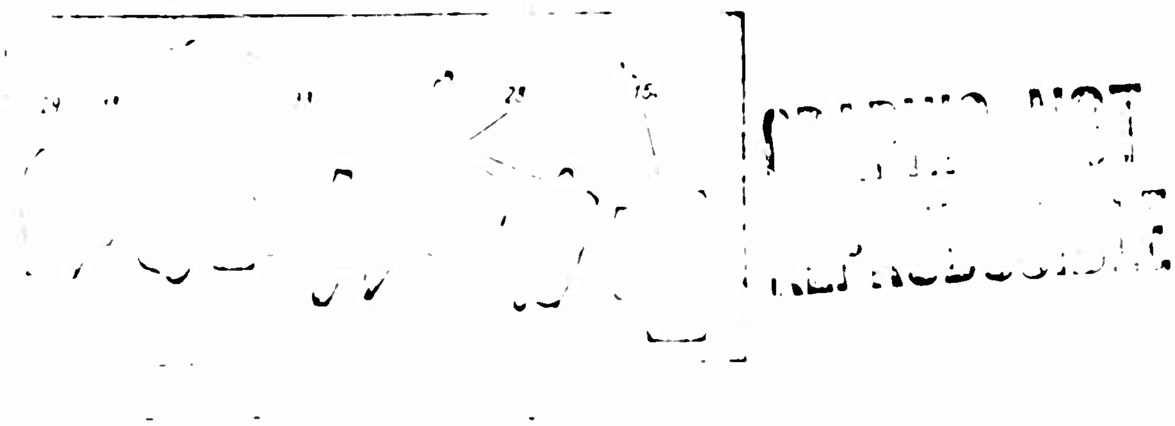

Fig. 5. The horizontal axis system

[illegible] - turntable bearing; 15 - vertical turntable housing; 33 - mounting of vertical dial alidade prism; 28 - telescope socket; 16 - micrometer bearing.

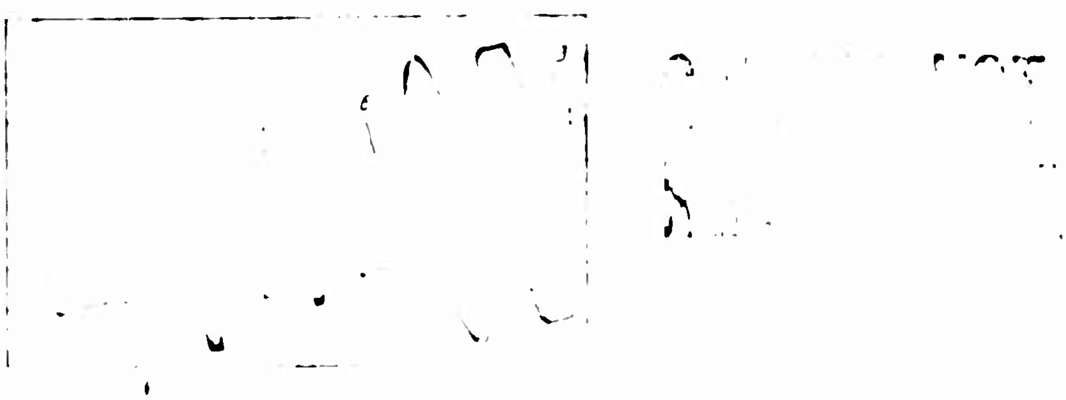

Fig. 6. The vertical axis system

1 - mounting for the second component of the objective of the horizontal dial microscope; 2 - mounting for the first component of the objective of the horizontal dial microscope; 3 - mounting of the alidade prism of the horizontal dial; 4 - the vertical axis; 5 - vertical axis main bearing; 6 - dial bush

## 4. Optical micrometer

The optical micrometer takes readings of the horizontal and vertical dials. The horizontal dial is graduated every four minutes, the seconds dial of the micrometer has 600 divisions and one revolution of the seconds disc corresponds to 2' and therefore the calibration of the seconds disc is 0.2" per division. The optical micrometer (Fig.7) is constructed as follows: three main parts are fixed to the micrometer housing 1; (a) the spiral assembly; (b) the micrometer bridge and (c) the lever bridge. The spiral assembly consists of the cam-shaft 2, the seconds disc 3, the cam 4, and the micrometer knob 15 (Fig.1). The seconds disc is attached to the cam shaft by nuts and washers. The cam shaft fits in a hole in the cam and is secured by a screw. The cylindrical part of the cam on which the spiral is cut runs in a hole in the micrometer housing; the micrometer knob is screwed to the threaded part of the cam (from the face side of the micrometer housing ) and is locked by a screw.

GRAPHIC NOT REPRODUCIBLE

Fig. 7. Optical micrometer

1 - micrometer housing; a - spiral assembly; b - micrometer bridge; c - lever bridge.

The micrometer bridge is secured to the micrometer housing by screws, and contains: the separating unit 26,27 (see Fig.3), the prism which transmits the images of the dial graduations 28, the lighting prism for the seconds disc 34 and the collecting lens 29.

The lever bridge is also secured by screws to the micrometer housing. At one end the micrometer levers run in holes in the lever bridge housing and at the other in holes in the micrometer housing. The micrometer levers carry plane-parallel plates and their driving pins run in the micrometer cam spiral.

The micrometer operates as follows: in taking a dial reading the images of diametrically opposite graduations of the dial must be made to coincide. This is done by turning the micrometer knob which turns the spiral and the seconds disc. The lever guide pins then run up the spiral, alter the positions of the levers and of the plane-parallel plates which are in the path of the light from the diametrically opposite dial graduations. As the plane-parallel plates are at an angle the light is deflected until the images of the diametrically opposite dial graduations coincide. When the images have coincided readings are taken from the dial and the seconds disc.

Chapter 2

# A BRIEF DESCRIPTION OF THEODOLITE ASSEMBLY

## 5. Manufacture of axial systems

A description of the process of assembling an optical theodolite would be very long and, therefore, we describe only the assembly of the main sub-assemblies and the preliminary assembly of the instrument.

The most important metal parts and components of the theodolite are the vertical and horizontal axis systems. Manufacture of the parts of the horizontal axis is a complicated process which calls for great accuracy in order that the parts shall fit on assembly. Manufacture of the components of the vertical axis (the axis, its main bearing, the dial bush, see Fig.6) is also a complicated process in which particular attention must be paid to grinding and lapping in.

The requirements which apply to the components are very severe, for example, the eccentricity of the dial-bearing part of the dial bush relative to the centre line of the part should not exceed 0.002 mm and the clearances between the axis and its main bearing and between the main bearing and the dial bush should not exceed 0.002 mm.

The axis and main bearing are made of steel grade 38 KhMYuA and their general method of manufacture is as follows. The blanks are annealed at a temperature of 820-850°C for three hours and are then cooled in the furnace to 400°C. They are rough machined leaving an allowance of 2-5 mm and are then heat treated by hardening at 950°C using oil and water as the cooling medium and tempering at 600°C - 650°C using air as cooling medium. The hardness on the $R_c$ scale should be not less than 23. After heat treatment, parts are finish machined except for places which require grinding with an allowance of 0.6-0.7 mm. The telescope socket is particularly difficult to machine.

The components are then given a stabilising tempering at +125°C for six hours with cooling in the furnace to relieve stresses and to prevent subsequent strain. Surfaces requiring it are then ground with an allowance of 0.2 mm on the diameter; they are drilled, bored, threads are cut, etc.

Protective coatings are applied to the telescope socket and to the vertical turntable housing at places which should not be nitrided and local nitriding is then applied. Nitriding gives a surface hardness of about 81-84 on the $R_a$ scale and the depth of the nitrided layer is 0.5 mm. The parts are then painted and finish ground with allowance for lapping.

The parts are again carefully inspected after the final grinding as alignment and parallelism tolerances for surfaces are often of the order of 0.001-0.002 mm. The inspected parts are made up into sets.

After finish grinding of the holes (the telescope socket, the vertical turntable housing, the vertical axis main bearing and dial bushes) they are lapped with suitable materials and checked for alignment and eccentricity. Only then is the turntable bearing surface finish ground with the vertical turntable housing, the micrometer bearing with the telescope socket and the vertical axis with its main bearing, leaving lapping allowances. The parts are then lapped with emeries from No.160 to No.240.

The bearings and vertical axis of the instrument are finally polished to mirror finish with a paste containing chromium oxide. After lapping, the axial systems are made up into sets and finally inspected for clearances, alignments, quality of lapping, etc.

6. Assembly of lower part of theodolite

The process of assembling the lower part of the theodolite, like that of the other parts, consists of preliminary assembly before the parts have been finished and final assembly afterwards. The object of the preliminary assembly is to match the parts and to seat them to one another. The carrier base is secured to the carrier by screws and then the carrier is mounted in a lathe and is screwed on to the mounting thread which is held in the lathe chuck, then holes are turned in the bottom of the carrier and a ring is cut under the mounting of the illuminating prism and condenser.

The clamping sleeve is screwed on to the carrier, the alidade clamp of the horizontal dial is assembled and the clamp is lapped with the clamp bush. When the levelling screws are assembled their threads are lapped to give smooth running. The mechanisms for moving the dials and the illuminating sleeve and contact are attached to the carrier.

The lenses of the horizontal dial microscope objective are rolled into their mounting on a lathe with special fittings. The slots in the mountings of the alidade prisms of the horizontal dials are matched to the prisms, drilled and holes are cut under the lock and adjusting screws. The assemblies are then dismantled, marked with the number of the carrier, and sent for plating and painting.

After the components have been finished the adjusting plate, the levelling screws, the horizontal dial alidade clamp, the illuminating sleeve with contact and other sub-assemblies are finally assembled.

Drills are passed through holes in the vertical axis main bearing to mark out and drill holes in the carrier, holes under the screw-threads in the half-rings which form the bearing for the dial sleeve, and also threads are cut in the half-rings under the screws to secure the vertical axis main bearing to the carrier and to the half-rings.

The contact ring and clamping sleeve are attached to the carrier, the electrical parts are assembled, the plug socket and mounting with lighting prism and condenser are attached to the bottom of the carrier.

## 7. Assembly of the centre part of the theodolite

Preliminary assembly of the centre part of the theodolite consists in matching the mountings for the optical components, in fitting the assemblies on the stand, in lapping the telescope adjusting screws and the level-setting screw to ensure smooth running and in assembly of the alidade levels of the horizontal dial. The positions of the holes under the thread for the screws which fix the vertical axis to the instrument stand are marked out and later drilled through holes in the vertical axis.

To mark out the holes the mounting of the alidade prisms is inserted in the vertical axis and then the mounting and axis together are screwed into the stand. Marking out of the holes to be drilled in the stand is done with a drill which runs through and fits the holes in the vertical axis. After the holes have been tapped the vertical axis is secured to the stand by four screws and the alignment is checked by screwing the mounting for the horizontal dial alidade prisms into the stand.

Holes in the swivelling prism of the horizontal dial microscope are used to mark out, drill and tap the holes for the screws which fix the mounting to the stand. The mounting with the prism is then fitted in the stand. The guide plate is secured to the alidade guide. The dial image selector mechanism is assembled on the wall of the right-hand upright of the stand. Holes for the screws which secure the wall to the stand are marked out through holes in the walls, and then drilled and tapped and then the selector prism is fitted and the wall with the selector mechanism is fixed in the right-hand upright of the stand (CL) by screws. A mounting with cover glass is screwed to the other side of this column.

The screw which sets the vertical turntable level is assembled on the left-hand upright and the telescope adjustment screw on the right-hand one.

The horizontal dial alidade level in its mounting is fixed to the lower part of the stand in such a way that the level adjustment screw is on the left-hand upright to which the mounting of the swivelling prism of the vertical dial microscope 12 has previously been fitted and the mounting for the components of the vertical dial microscope objective 13 (Fig.3) are screwed in.

## 8. Assembly of the upper part of the theodolite

This part of the instrument is the most difficult to manufacture and assemble. The principal components of the upper part of the theodolite are: the horizontal axis system, the telescope, the optical micrometer, the alidade level of the vertical turntable, the telescope clamp and the reading microscope.

Preliminary assembly consists in lapping the telescope seating in the telescope socket until the hole in the telescope wall is opposite the bearing of the vertical turntable. The telescope clamp is lapped in its seating and the mounting of the focussing component of the telescope objective is lapped in after which the focussing lens (focussing component) is fixed in its mounting.

The telescope is finally fixed in its socket, the casing is fitted on it and then the mechanism which moves the focussing lens mounting is assembled. This consists of a threaded slide block and focussing ring, then the stirrup which secures the reading microscope to the telescope is fitted, the mounting with the graticule adjusting screws is fitted and the eyepiece is screwed in. Finally, the telescope is adjusted and assembled.

Holes are cut in the clamp of the vertical dial alidade levels at the diameter of bearing of the mountings for the vertical dial alidade prisms. The lighting mounting is fitted, after which the frame with level and prism system which transmits the image of the ends of the bubble is fixed to the level clamp.

The first component of the microscope objective 11 (see Fig.3) in its mounting is first installed in the mounting of the vertical dial alidade prisms, and then the alidade prisms 10 are pre-assembled and are secured by screws to the mounting for the condenser 7, the lighting prism 6 and the prism 2. The components are previously wired, the electric wire is passed through the base and the turntable bearing.

The prism of the reading microscope 30 is fitted in its mounting and fitted into the telescope socket. Finally the reading microscope is assembled, passed through the stirrup and screwed into the telescope socket. All the upper part of the theodolite is finally assembled after adjustment.

9. Assembly of the optical micrometer

Assembly of the optical micrometer commences with fitting of the lever bridges in the micrometer mounting. The holes under the cam are lapped to ensure smooth running without rocking. Preliminary assembly consists in fitting the micrometer bridge and levers, and in fitting the springs which press the lever guide pins against the spiral surface of the cam. These parts are then dismantled and marked with the micrometer mounting number and sent for finishing.

After the micrometer has been adjusted the plane-parallel plates are fixed into the lever seatings.

The following optical parts are fitted on the micrometer bridge: the dividing unit, the prism which transmits the images of the dial graduations, the prism for illuminating the seconds disc, the collecting lens of the reading microscope and the seconds disc which is fitted to the cam shaft.

The optical micrometer is finally assembled after the sub-assemblies have been adjusted and laboratory tests have been made.

## Chapter 3

## TESTING THEODOLITE OT-02 BEFORE STARTING WORK

### 10. Checking the travel of the levelling and micrometer screws

Before proceeding to work, check the travel of the levelling and micrometer screws, the travel of the instrument axes, the level in the stand, and examine the tripod. The levelling and micrometer screws should travel freely without rocking or binding. The travel of the levelling screws is corrected by the adjusting screws, the travel of the micrometer adjusting screws is adjusted by springs in the nuts and washers of the adjusting screws.

### 11. Checking the instrument axes

The instrument axes should rotate freely and smoothly without binding or rocking. After the alidades of the horizontal dial have been turned 360° about a vertical axis the level bubble on the stand should not have moved by more than 1.5 divisions. Excessive oscillations of the vertical axis can only be corrected in the factory.

### 12. Checking the level in the stand

The cylindrical level of the horizontal dial alidade is checked in the usual way. The level is first aligned in the direction of the two levelling screws, the bubble is brought to the centre and then the alidade is turned through 180°. If there is any change in the level, half the correction is made by the level adjusting screw and the other half by the levelling screws. Checking is continued until the bubble remains in the centre on turning through 180°.

## 13. Examination of tripod

Before commencing work examine all the joints in the metal and wooden parts of the tripod. It is very important to ensure that there is no play at the places where the tips are joined to the knife edges of the tripod.

## 14. Checking the quality of the image in the telescope objective

Besides making the checks mentioned above, if the theodolite has been roughly handled in transit or if the adjustment has been disturbed, check the quality of the images of the telescope objective, the microscopes of the horizontal and vertical dials, check the setting of the graticule in the telescope and the vertical turntable level, the angle between the horizontal axis and the vertical axis of rotation of the instrument, the magnitude of the collimation error, the travel of the focussing lens, the eccentricity of the dial and alidade, and the run of the dial microscopes.

The telescope objective image should be sharp over two-thirds of the field of vision. This may be checked by examining a sharply outlined, distant object against the background of the sky.

The centering of the telescope optical system is checked by examination of a star. The tube focussing is altered and the image of the star is observed. In a well-centered system the image of the star should be a true circle both before and behind the focal plane of the system.

### 15. Checking the microscopes of the horizontal and vertical dials

The quality of the image of the horizontal dial microscope is first checked, particular attention being paid to the following.

1. When the seconds disc is set to the zero mark the index of the optical micrometer should either coincide with the combined images of the diametrically opposite dial graduations or should be half-way between them.

2. There must be no darkening of the edges of the field of the reading microscope and the illumination should be uniform over the whole field of vision.

3. The line of separation between the upper and lower images of the disc graduations should be fine, straight and without noticeable thickening.

4. The images of the dial calibration must not be bent.

5. The images of calibration lines of the dial and the seconds disc should both be visibly sharp and together without refocussing the eyepiece.

The vertical dial microscope is checked in just the same way as that of the horizontal dial.

### 16. Checking the setting of the telescope graticule

The telescope graticule is checked with a plummet and corrected with the adjusting screws.

### 17. Checking the angle between the horizontal and vertical axes of rotation of the instrument

The horizontal axis of theodolite OT-02 should be perpendicular to the vertical axis. Therefore, the theodolite is carefully checked for the level of the horizontal dial alidade and the position of the bisector is observed relative to the plumb line when the telescope is turned about the horizontal axis; corrections can only be made in the workshop or factory.

### 18. Checking the vertical turntable level

The position of the zenith is determined in the usual way and corrected by the level adjusting screw 26 (Fig.1). The vertical turntable is sub-divided into sectors as shown in Fig.8. It may be seen through the reading microscope (with CR) that the numbers marked against the graduations increase in the counter-clockwise direction in the right-hand upper sector and diminish in the clockwise direction in the lower right-hand sector. The optical axis of the telescope is horizontal when the vertical dial reading is 90-90°. The sum of the readings with CR and CL should be 180°, otherwise it indicates that $M_z$ is not zero.

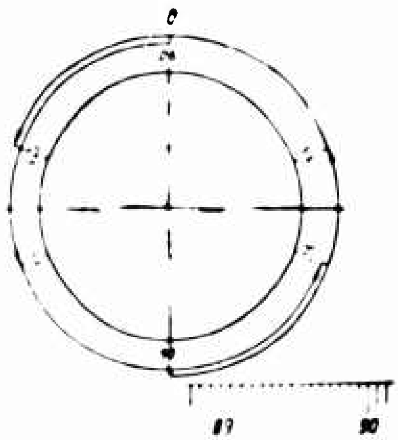


Fig. 5. Diagram of vertical scale arrangement

## 19. Correction of collimation error

Collimation error is determined in the usual way: displacement of the graticule mounting is corrected, when this is done the graticule adjusting screws should not be turned too far so as to avoid strain which could alter the collimation error. When the collimation error has been corrected check that the graticule setting is not disturbed relative to the plummet.

## 20. Checking the travel of the focussing lens

Incorrect travel of the focussing lens causes an error which is equivalent in effect to telescope collimation error. The magnitude of this error is determined in the following way: the telescope is first aimed at a remote point, preferably on the horizon, and then the mounting of the focussing lens will be close to one extreme position. The tube is then aimed at a scale which is at a distance of 5–6 metres from the theodolite, and then the focussing lens mounting will be close to the other extreme position. Then transit the tube through the zenith and repeat the procedure.

The difference between the readings (with the two psoitions of the turntable) on the remote point ($CL_1 - CR_1 = 2c_1$) and on the scale ($CL_2 - CR_2 = 2c_2$) gives twice the error of travel of the focussing lens

$$2 \quad = 2c_2 - 2c_1 .$$

The error can be corrected only in the workshop or at the works.

## 21. Checking the eccentricity of dial and alidade

The eccentricity of dial and alidade is determined from the difference between micrometer readings when diametrically opposite gra uations are made to coincide and when one of them is made to coincide with the micrometer index. Eccentricity can be corrected only in the workshop or the factory. The procedure for determining the eccentricity is described in the special literature.*

## 22. Checking the run of the microscopes

The magnitude of the run is determined in the following way:** make the zero mark on the seconds disc coincide with the index of

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* Ch.Yu. Vitozhents. Methods of investigating optical theodolites, Moscow, 1947.

** Instruction for first-class triangulation, 3rd edition, Moscow, Geodezizdat, 1939.

micrometer; make images of diametrically opposite graduations of the disc coincide by turning the adjusting screw of the horizontal dial alidade; displace the images of the disc graduations by one division until again the diametrically opposite graduations again coincide by rotating the micrometer knob.

The reading on the seconds disc should then be 60, if it is more or less than 60 then run is present and this can be corrected only in the workshop or at the factory.

## 23. Investigation of the optical micrometer

Investigation of systematic errors of the optical micrometer

To make the investigation, measure a small angle with the theodolite, make the measurement a whole number of times within the range of the complete scale of the seconds disc of the optical micrometer.

In the process of measuring the angle the images of the same graduation lines of the horizontal dial are made to coincide; between settings reset the dial in such a way that when the telescope is brought up from the left- or right-hand side the micrometer readings differ by 15 divisions of the seconds disc. Altogether, four forward and four reverse movements are made in four settings.

Make the micrometer readings and work out the results of the measurement by the procedure described in the Instructions on Triangulation, Classes 1,2,3 and 4 (1955 edition, p.100).

Take the mean value of v of the four readings obtained at each setting; it should not exceed one second.

During the production of theodolite OT-02 under works laboratory conditions, systematic errors of the optical micrometer are examined by the collimator graticule with a scale division of the order of 11 seconds per division of the seconds disc.

Determination of errors of coincidence of dial graduation images

Errors of coincidence depend mainly on the experience of the observer and, therefore, cannot always be attributed to defects in the theodolite. Determine the error of coincidence of images of calibration lines on the dial with various settings of the horizontal and vertical dial alidades, using two coincidences for each and record the differences between the corresponding micrometer readings. The order in which the readings are taken and the method of working them out are given in the Instructions on Triangulation, Classes 1,2,3 and 4 (1955 edition, p.101).

The standard error of a single coincidence of images of graduation lines in theodolite OT-02 should not exceed 0.3 seconds for the horizontal dial microscope or 0.6 seconds for the vertical dial microscope.

Determination of backlash in the optical micrometer

Backlash in the optical micrometer is determined with various settings of the horizontal dial. Make the images of the lines coincide twice: once when the seconds disc is rotated clockwise and once counter-clockwise.

Between individual settings turn the alidade through 15 degrees and the seconds disc through 5 seconds. The mean of the difference 'right minus left' characterises the systematic part of the optical micrometer backlash and the standard error of the mean difference characterises the error of determination. In theodolite

CT-02 individual 'right minus left' differences should be from -1 second to +1 second. The order in which the readings are taken and the method of working them out are given in the Instruction on Triangulation, Classes 1,2,3 and 4 (1955 edition, p.102).

### 24. Investigation of total diameter errors of horizontal dial

The total diameter errors of the horizontal dial of theodolite CT-02 determined by the method proposed by S.I. Eliseyev, by measuring the angle between two collimators; the determination is repeated after major overhaul. Examine the dial at intervals of 3° and measure angles of 36, 45 and 60° in individual series at different places on the dial.

For example, the first series for the angle 36° includes measurements made with initial settings of 0, 36, 72, 108 and 144°. The angles are measured with the following initial settings.

| Angle 36° | Angle 45° | Angle 60° |
|---|---|---|
| 0° + $\varphi$ | 0° + $\varphi$ | 0° + $\varphi$ |
| 36° + $\varphi$ | 45° + $\varphi$ | 60° + $\varphi$ |
| 72° + $\varphi$ | 90° + $\varphi$ | 120° + $\varphi$ |
| 108° + $\varphi$ | 135° + $\varphi$ | |
| 144° + $\varphi$ | | |

where the value of $\varphi$ is 0;3;6;9;...177.

Thus the programme of measurement of each angle includes 60 series. Two angle measurements are made for each setting of the dial. The measurements of a particular series are made in the ordinary way, continuously, one after another: one series is made first in the direction indicated and then the second series in the reverse sequence.

Determine the mean value of the measured angle C for each series. For instance, for $C \sim 60$ degrees $\varphi = 3$ degrees

$$C = \frac{A_3 + A_{63} + A_{123}}{3},$$

where A3 is the value of the angle C measured with the initial setting of $3^{\circ}$ etc. The following differences are also calculated

$$\Gamma_3 = C - A_3; \qquad \Gamma_{63} = C - A_{63}; \qquad \Gamma_{123} = C - A_{123}.$$

The index '6' indicates how many times the angle C is laid out round the circumference. The differences 1 which are obtained are used with the corresponding formulae to determine the diameter correction $\varphi$. This correction is the mean of the diameter correction corresponding to the graduation $\varphi$ and the adjacent graduation.

$$1.\quad \omega^{10}_{\varphi} = \frac{-2\Gamma^{10}_{\varphi} - \Gamma^{10}_{\varphi+36} + \Gamma^{10}_{\varphi+108} + 2\Gamma^{10}_{\varphi+144}}{5}$$

$$2.\quad \omega^{8}_{\varphi} = \frac{-2\Gamma^{8}_{\varphi} - \Gamma^{8}_{\varphi+45} + \Gamma^{8}_{\varphi+135}}{4}$$

$$3.\quad \omega^{6}_{\varphi} = \frac{-2\Gamma^{6}_{\varphi} - \Gamma^{6}_{\varphi+60}}{3}$$

$$4.\quad \omega^{6,10}_{\varphi} = \frac{\omega^{6}_{\varphi} + \omega^{6}_{\varphi+36} + \omega^{6}_{\varphi+72} + \omega^{6}_{\varphi+108} + \omega^{6}_{\varphi+144}}{5}$$

$$5.\quad \omega^{10,6}_{\varphi} = \frac{\omega^{10}_{\varphi} + \omega^{10}_{\varphi+60} + \omega^{10}_{\varphi+120}}{3}$$

$$6.\quad \omega^{30}_{\varphi} = 0{,}4\omega^{10}_{\varphi} + 0{,}4\omega^{6,10}_{\varphi} + 0{,}6\omega^{6}_{\varphi} + 0{,}6\omega^{10,6}_{\varphi}$$

$$7.\quad \omega^{8,30}_{\varphi} = \frac{\omega^{8}_{\varphi} + \omega^{8}_{\varphi+12} + \omega^{8}_{\varphi+24} + \ldots + \omega^{8}_{\varphi+156} + \omega^{8}_{\varphi+168}}{15}$$

$$8.\quad \omega^{30'}_{\varphi} = \frac{\omega^{30}_{\varphi} + \omega^{30}_{\varphi+45} + \omega^{30}_{\varphi+90} + \omega^{30}_{\varphi+135}}{4}$$

$$9.\quad (\varphi) = \frac{1}{3}\,\omega^{6}_{\varphi} + \frac{1}{3}\,\omega^{30'}_{\varphi} + \frac{2}{3}\,\Sigma\,\omega^{30}_{\varphi} - \frac{2}{3}\,\omega^{a30}_{\varphi}$$

The control formulae are as follows.

$$\Sigma\omega^{10}_{\varphi} = \Sigma\omega^{5}_{\varphi} = \Sigma\omega^{6}_{\varphi} = \Sigma\omega^{30}_{\varphi} = \Sigma(\varphi) = 0.$$

The total diameter errors of optical theodolite dials type OT-02 should not exceed $\pm 1''.5$.

## 25. Investigation of short period errors of division of the horizontal dial of theodolite OT-02

More detailed investigation of dials indicates that diameter errors which lie within the ranges between which determinations are made vary in a periodic manner, with a period which is shorter than the interval between diameters investigated. Therefore, these errors and their periodicity cannot be determined if the dial diameters are investigated over a comparatively large interval (5, 3 or 1°). Errors of this kind are called short period errors.

By the error of an interval between adjacent graduations on the dial we mean the difference between the nominal and true values. Short period errors result from errors in the guide screw of the dividing machine and also from incorrect cutting of the threads. This latter is particularly important in graduating metal dials. In investigating optical theodolite OT-02 attention must be directed to the order of setting of the alidade. For example, in order to measure the intervals $0^{\circ}0'-0^{\circ}4'$ and $180^{\circ}0'-180^{\circ}4'$ by means of the optical micrometer, set the seconds disc of the micrometer to zero and make the diametrically opposite lines of $0^{\circ}4'$ and $180^{\circ}4'$ coincide approximately by turning the alidade, then take readings. The short-period error should not exceed $\pm1.5''$. The sequence in which readings should be made and the method of working them out are given in the <u>Instructions on Triangulation</u>, Classes 1,2,3 and 4 (1955 edition, p.113).

## Chapter 4

## CHECKING OF THEODOLITE OT-02 DURING MANUFACTURE AND REPAIR

### 26. Fitting the horizontal dial

The process of final assembly and adjustment of an optical theodolite includes: fitting of the horizontal dial, fitting of the vertical dial, assembly and adjustment of the telescope objective, adjustment of the optical micrometer, adjustment of the reading micrometer prism, adjustment of the optical system of the horizontal dial microscope, checking that the telescope horizontal axis is perpendicular to the vertical axis of the theodolite, adjusting the optical system of the vertical dial microscope, fitting of the dioptric ring, fitting of the graticule, determination of $M_z$ of the vertical dial, checking the collimation error.

When the dial is fitted it is centered on the dial-bush relative to the vertical axis of the instrument with the following conditions that the eccentricity of the horizontal dial should not exceed 10" and of the alidade 20".

A device which is used to centre the dials is illustrated in Fig.9. The base-plate is supported on three levelling screws and carries two base-blocks. On each base-block there is a microscope upright and the microscope can be moved radially or vertically by rack and pinion. The microscope uprights are set on a straight line which passes through the centre of the device. The knob 'a' is turned to drive the microscopes radially and the knob 'b' is turned to drive them vertically. The microscopes are provided with micrometers. The graduations on the dials are illuminated by lamps in the holder 'c'. Special screws 'd' with ebonite tips are used to drive the horizontal dial. To centre the horizontal dial the vertical axis of the instrument is set up on the device shown in Fig.9 by four screws. A separator is fitted to the axis and balls are poured in quickly. Then the vertical axis main bearing is connected to the dial bush by a special ring and half-ring which run in the dial bush.

GRAPHIC NOT REPRODUCIBLE

Fig. 9. Special device for fitting the horizontal dial of theodolite OT-02
a - upright drive knob; b - microscope drive knob; c - lighting fitting; d - dial feed screw

First of all the dial is fitted on the dial bush and fixed with four clamps. Then the vertical axis main bearing and dial bush with dial are fitted on the axis, the clamp is fitted on the vertical axis main bearing and connected to the base plate of the device. In this way, the dial bush and dial can be turned relative to the vertical axis main bearing.

The microscopes are focussed to give sharp readings of the graduations and then the dial itself is centered by turning the dial bush with the dial relative to the vertical axis main bearing and observing in the microscopes which are fitted with micrometers. The dial is displaced with respect to the dial bush by means of the special screws 'd'. The centering adjustment is continued until the eccentricity of the horizontal dial is not greater than 10" and of the alidades 20". Only then is the dial finally fixed to the sleeve with the four clamps. [illegible] the dial is being fixed, to avoid deforming it, it is checked for flatness by applying an optically flat test glass to the clamps and examining the interference pattern; the number of interference rings N should be not greater than 1-1.5.

The eccentricity of the alidades is checked on the same device by releasing the clamp which fixes the vertical axis main bearing and turning this bearing with the dial bush about the vertical axis. If the eccentricity is too great, for instance, by 20-30", then under field conditions the dial can be centered without removing it from the instrument. For this purpose, the fixing plate with levelling screws is removed from the carrier and so is the carrier base which carries the prism 17 and condenser 18 (Fig.3). The theodolite is then set upside down on a wooden stand (see Fig.24). The gear knob assembly and protective cover 5 (Fig.1) are then removed from the carrier. The clamping screws of the casing which fixes the dial screws are reached through holes in the carrier. These screws are removed and the dial screws are slightly loosened, the dial is displaced in the required direction whilst under observation in the reading microscope. To avoid eccentricity the dial is fixed with the screws and provided that the dial has not been displaced the dial screws are finally secured to the special casings with the clamping screws, by access through holes in the carrier. After this the gear knob assembly with protective cover and the carrier base with levelling screws are assembled on the carrier.

## 27. Fitting of vertical dial

The turntable bearing mounting is set up on the device shown in Fig.10. The vertical dial is first fitted in the vertical turntable housing in such a way that diametrically opposite graduations ($0^0$ - $90^0$) appear through the centres of the holes in the vertical turntable housing. This subsequently simplifies location of the zenith of the vertical dial. Then the turntable bearing is placed in the vertical turntable housing and the entire assembly is set up on the fitting shown in Fig.10.

The microscopes are focussed on the graduations and the vertical dial is centered by displacing it relative to the centre line of the turntable bearing in the vertical turntable housing.

The vertical dial is displaced with a wooden rod, its eccentricity should not exceed 20". After centering the vertical dial the spring washer is finally clamped with screws.

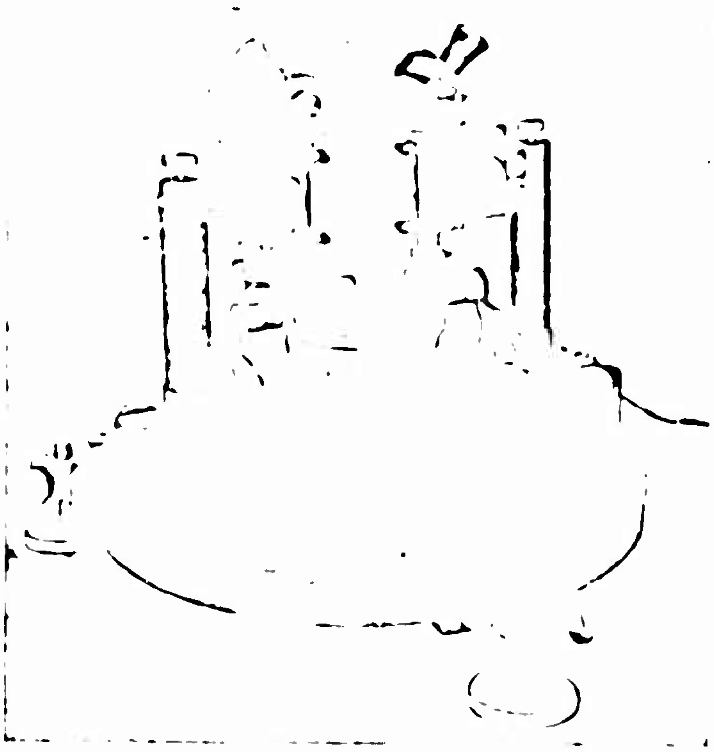

Fig. 10. Special device for fitting the vertical dial of theodolite OT-02

## 28. Assembly and adjustment of the telescope objective

The process of adjustment of the five lens tele-objective of the telescope system consists in careful centering and accurate fitting of the actual objective lenses (the first three lenses) at a certain distance apart. The objective must be assembled and adjusted in such a way that these requirements are met. The air gaps between the lenses of the actual objective are set on the centre line of the system by appropriately locating the coordinate points of the system.

Let us determine the influence on the equivalent focal length of alteration in the distances (or air gaps) between lenses of the actual objective. For simplicity we consider the case when two combined systems have a common central line, Fig.11.

It is known, from geometric optics, that the rear equivalent focal length is:

$$f' = -\frac{f'_1 f'_2}{\Delta}$$

and the optical interval

$$\Delta = d - f'_1 + f_2.$$

so that

$$f' = \frac{f'_1 f'_2}{f'_1 + f'_2 - d}. \qquad (1)$$

From equation (1) we find the relationship between the rear equivalent focal length f' and the distance between lenses d . Formula (1) is modified somewhat in order to determine the effect on f' of a change of d .

$$f'_1 f' + f'_2 f' - f'd = f'_1 f'_2.$$

Dividing both halves of the equation by f' we have

$$f'_1 + f'_2 - \frac{f'_1 f'_2}{f'} = d. \qquad (2)$$

Differentiating, we obtain:

$$\frac{\partial f'}{\partial d} = \frac{f'^2}{f'_1 f'_2}.$$

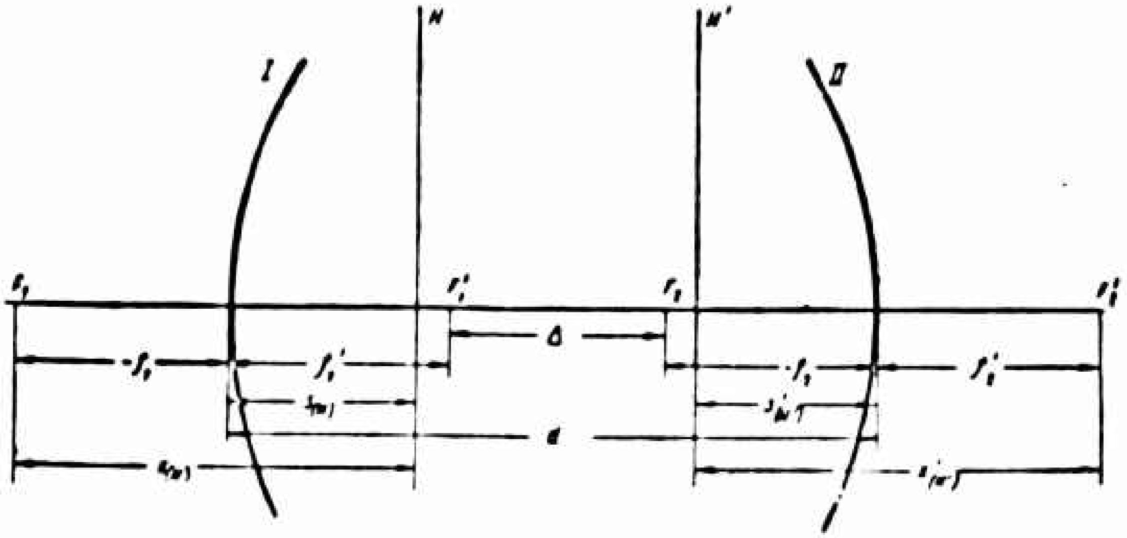


Fig. 11.

whence

$$\partial f' = \frac{f'^2}{f'_1 f'_2} \partial d. \tag{3}$$

From formula (3) we can determine the change in the rear equivalent focal length as a function of change in the distance between lenses (or air gap). Since the quantities $f'$, $f'_1$ and $f'_2$ are constant for the given system, formula (3) may be written in the form:

$$\partial f' = k \cdot \partial d, \tag{4}$$

where

$$\text{где } k = \frac{f'^2}{f'_1 f'_2}.$$

If the actual objective has three lenses, first find by formula (1) the rear equivalent focal length of the first two lenses and solve the problems of focussing the first two lenses. Then solve the same problem for the system of a lens which is equivalent to the first two together with the third lens. By way of check the actual objective is checked for focus and quality of image.

If the data required for the calculation are available the process of setting the air gaps between the lenses of the actual objective (on the system and centre line) is carried out in the following way. Lens 3 - 90, the spacer ring 3 - 91, and the lens 3 - 92 are inserted into the objective mounting (Fig.12). The thickness $D_2$ is measured on the objective centre-line, using a precision spherometer or a universal microscope. As the thicknesses of the lenses 3 - 90 and 3 - 92 are known we may calculate the air gap $b_2 = D_2 - (d_2 + d_3)$. The calculated air gap of 4.046 gives the necessary thickness of the ring 3 - 91, and $d_2$, $d_3$ and $D_2$ are measured to an accuracy of 0.002 mm. If $b_2$ is greater than 4.046, turn down the spacer ring 3 - 91 and to measure again bear in mind that the maximum tolerance on the air gap is 0.005 mm.

Fig. 12. 2nd and 3rd telescope objective lenses in mounting

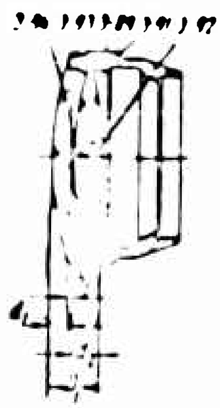

Fig. 13. 1st and 2nd telescope objective lenses in mounting

Having measured the air gap between the lenses 3 - 90 and 3 - 92, remove the lenses from the mounting and set the air gap $b_1$ (Fig.13). The spacer ring 3 - 91, the lens 3 - 92, the spacer ring 3 - 93, and the lens 3 - 94 are inserted into the mounting, the quantity $D_1$ is measured and the air gap is calculated as $b_1 = D_1 - (d_1 + d_2)$. The calculated air gap of 1.22 ± 0.02 is obtained by turning down the seating of ring 3 - 93 under the lens 3 - 94; $d_1$, $d_2$ and $D_1$ are measured to within 0.005 mm.

An image of good quality is obtained when the measured and calculated values of the air gaps are in agreement. Special

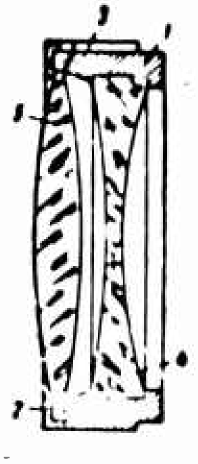

Fig. 14. 2nd and 3rd objective lenses in special housing

1 - housing; 2 - retaining ring; 3 - spacer ring; 4 - 3rd objective lens; 5 - 2nd objective lens.

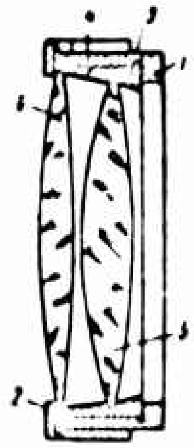

Fig. 15. 1st and 2nd objective lenses in special housing

1 - housing; 2 - retaining ring; 3 - spacer ring; 4 - spacer ring; 5 - 2nd objective lens, 6 - 1st objective lens.

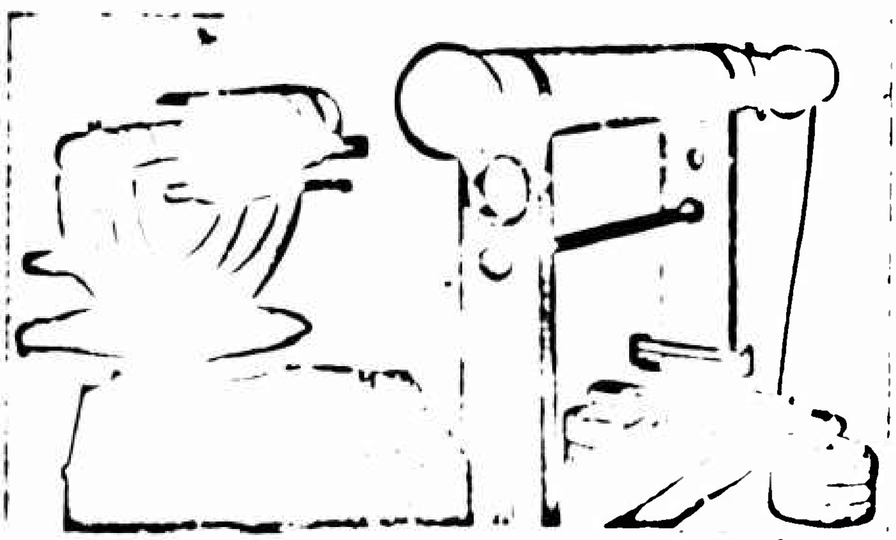

Fig. 16. Optical bench

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housings (Figs. 14,15) are used for convenience in measuring the air gaps. When the lenses have been fitted the mounting and the actual objective assembly are screwed into the telescope. The telescope is set up in a stand on an optical bench (Fig.16), the image of a point located at the focus of the collimator of the optical bench is observed in the telescope and the optical system of the telescope is centered by rotating the lenses of the actual objective relative to one another. On refocussing the image of the point should appear as a true circle, and this can be achieved provided that the parts have been made within tolerance.

After the telescope optical system has been centered a mirror is fitted at the collimator focus. The resolving capacity of the telescope objective is determined by looking into the telescope through the collimator. In the centre of the field this resolving capacity should be not greater than 2.5". The image given by the telescope objective should be sharp over two-thirds of the field of vision and the focussing component of the objective should move smoothly.

In adjusting the telescope objective it should be borne in mind that parallax is one of the defects of assembly and adjustment of instrument optical systems.

Parallax is the effect which is observed when the eye is displaced from one side of the lens to the other and the image of the object seen in the optical system moves relative to the cross on the graticule.

Parallax occurs because in the optical system of the instrument the focal plane of the objective does not coincide with

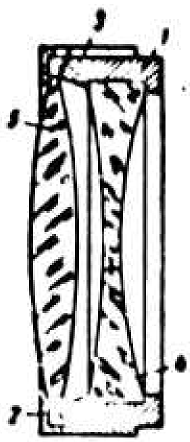


Fig. 14. 2nd and 3rd objective lenses in special housing

1 - housing; 2 - retaining ring; 3 - spacer ring; 4 - 3rd objective lens; 5 - 2nd objective lens.

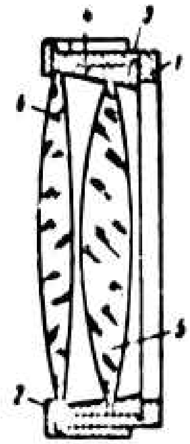


Fig. 15. 1st and 2nd objective lenses in special housing

1 - housing; 2 - retaining ring; 3 - spacer ring; 4 - spacer ring; 5 - 2nd objective lens; 6 - 1st objective lens.

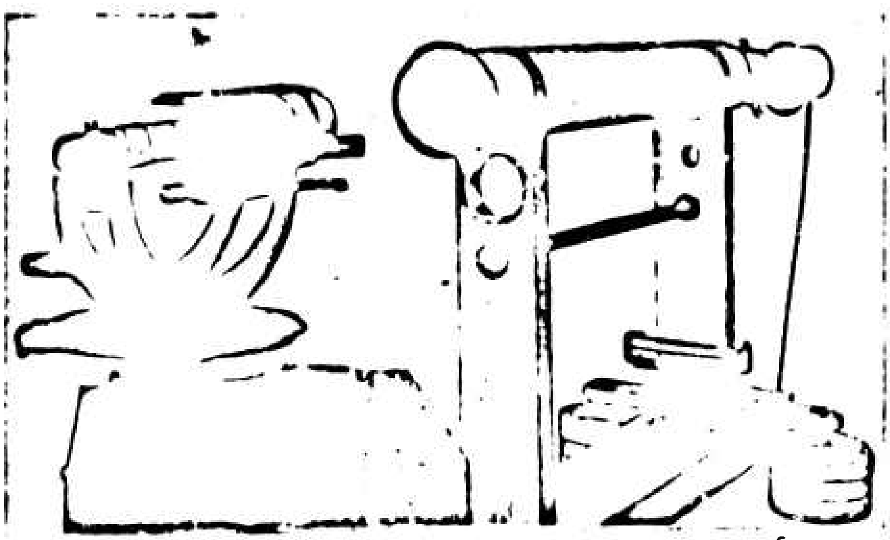

Fig. 16. Optical bench

that of the graticule. When parallax exceeds a certain amount it begins to have an important influence on the accuracy of observation. Parallax is easily avoided in telescopes with external focussing because the eyepiece and graticule together can be moved along the optical axis of the objective.

It is more difficult to correct parallax in telescopes with internal focussing because the distance between the actual objective and the graticule is constant. In this case, parallax is corrected by altering the distance between the actual objective and the graticule. For example, in the telescope of theodolite OT-02 this distance is altered by adjusting the spacer rings in the graticule mounting. Here, tolerances can only be positive.

To adjust the telescope it is necessary to know the relationship between the parallax angle $\alpha$ and the parallax displacement P along the tube axis. Suppose that W is the tube eyepiece (Fig.17), Z is the position of the outlet iris. The graticule cross is at the focus of the eyepiece O' . Suppose that the actual image given by the telescope objective (not shown on the figure) is observed not at the point O' but at the point K', so that it is displaced by an amount p . An observer whose eye is at the centre of the iris (position $Q_1$) sees the images of the points K' and O' covering one another on the centre line. If the eye is then moved to position $Q_2$ at the edge of the iris, since the point O" is at infinity and K" is at a certain distance the observer would see these two points on the lines MO" and MK" between which there is a certain angle $\alpha$ which is termed the parallax angle. Parallax is usually considered to be negative if

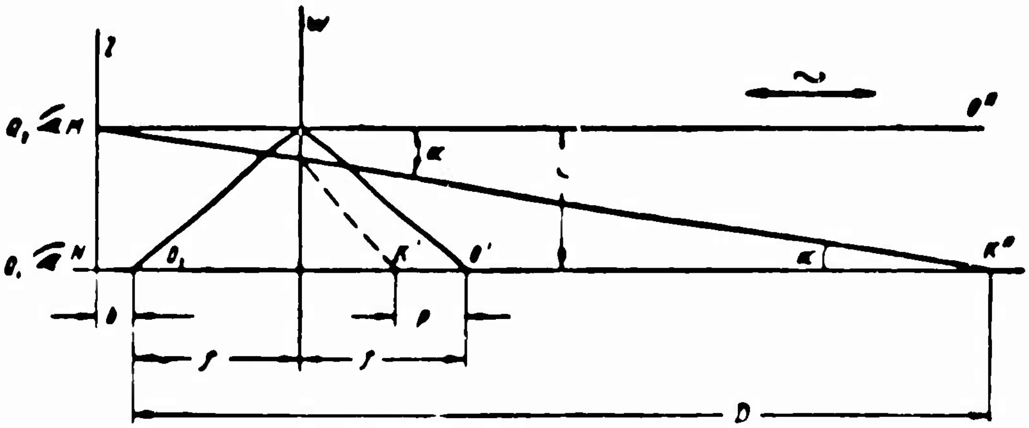

Fig. 17.

K' is in front of the focus O' (from the observer's side) and positive if K' is behind O' . Let us determine the effect of altering the parallax displacement p on the parallax angle $\alpha$ .

From the triangle MNK" we have:

$$(D+b)\,\mathrm{tg}\,\alpha = r,$$

where r is the radius of the 'iris'

$$D = O_1K'', \qquad b = O_1N.$$

But since the angle $\alpha$ is very small and D is great we may neglect b. Then

$$r = D\,\mathrm{tg}\,\alpha = \frac{D\alpha''}{206265}. \tag{5}$$

But from Newton's formula we have

$$D \cdot P = f^2. \tag{6}$$

where f is the focal length of the eyepiece and p is the parallax displacement.

From formula (5) we find:

$$D = \frac{r \cdot 206\,265}{\alpha''}. \tag{7}$$

and from formula (6)

$$D = \frac{f^2}{p}. \tag{8}$$

Thus

$$\frac{f^2}{p} = \frac{r \cdot 206\,265}{\alpha''}.$$

whence

$$p = \frac{f^2 \alpha}{r \cdot 206\,265}. \tag{9}$$

A similar formula was given by Malinovskiy in the journal Revue d'Optique, No.9, 1932. Equation (9) must be differentiated to determine the effect of altering the parallax displacement p on the parallax angle α . Since f and r are constant for a given system we have:

$$\frac{f^2}{r\rho''} = k = \frac{f^2}{r \cdot 206\,265}.$$

Then

$$p = k \cdot \alpha$$

or

$$\alpha = \frac{1}{k} p.$$

Differentiating, we obtain:

$$d\alpha = \frac{1}{k}\, dp. \tag{10}$$

Formula (10) can be used to determine the change in parallax angle α which results from change in the parallax displacement p . It follows from equation (9) that if the angle α is given a value equal to the resolving capacity of the eye we obtain the ultimate displacement p which is imperceptible to the eye.

When $\alpha = 30''$; $r = 1$ мм and $f = 10$ мм

$$p = \frac{f^2 \alpha}{r \cdot 206265} = \frac{100 \cdot 30}{1 \cdot 206265} = 0{,}015 \text{ мм}.$$

As may be seen from this example, the ultimate parallax displacement is comparatively small, being some hundredths of a millimetre and, therefore, in adjusting the optical systems of sight tubes with internal focussing it is necessary accurately to maintain the distance from the last surface of the actual objective to the telescope graticule.

## 29. Adjustment of the optical micrometer

Adjustment of the optical micrometer (see Fig.7) includes fitting of the components and assemblies and also laboratory investigations. The adjustment includes:

(1) fitting of the plane-parallel plates 25 (Fig.3),

(2) fitting optical parts in the micrometer bridge,

(3) fitting the illuminating prism of the seconds disc,

(4) testing the optical micrometer.

(1) To fit the plane-parallel plates of the optical micrometer the micrometer bridge with optical components (Fig.8) is removed and the micrometer housing is screwed into the threaded stand of a goniometer (Fig.19). The micrometer bearing is set on the micrometer mounting with a plane-parallel plate secured to the base of the micrometer bearing. After the plane-parallel plates have been fitted into the micrometer levers they are secured with fixing screws and shellac.

(2) In order to fit the optical parts in the micrometer bridge it is necessary to fit the prism 28 which transmits the images of the disc graduations and the separating unit 26,27 (see Fig.3). The micrometer bridge is set up on a plane-parallel plate which is placed, together with the autocollimator, on an inspection plate. The autocollimation image from the plates is

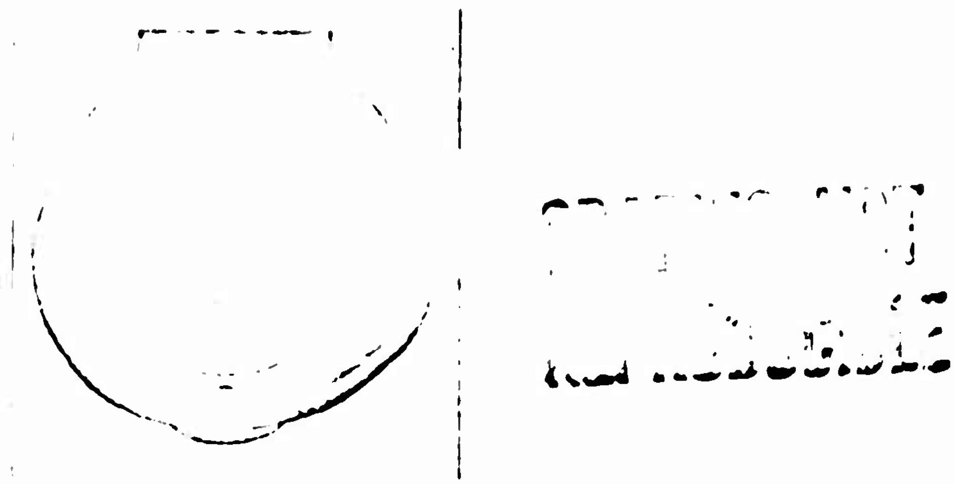

Fig. 18. Micrometer housing with lever bridge and spiral assembly

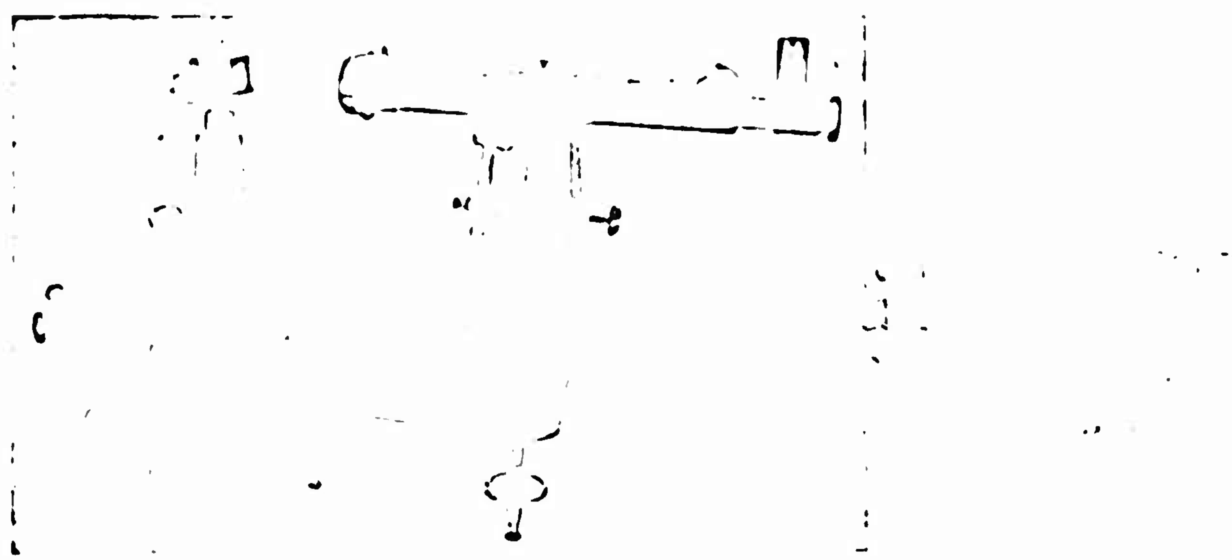

Fig. 19. Goniometer

observed, the micrometer bridge is brought up and the prism 28 (Fig.3) is so fitted that its exit face is parallel to the base of the micrometer bridge. The micrometer bridge is then set in the micrometer mounting to which a special mounting with the reading microscopes is fixed (Fig.20).

The separating unit is set by observing through the measuring microscopes. In order that the line of separation should be in the middle of the diaphragm aperture (the frame) on the prism 28, this prism must be moved perpendicular to the base of the micrometer bridge. After the prism 28 and the separating unit have been set they are locked in position.

(3) The illuminating prism of the seconds disc 34 is set whilst observing in the reading microscope which is held in a special mounting on the micrometer mounting (Fig.20). Whilst observing in the reading microscope the prism 34 is set by means of the adjusting screws so that the images of the graduations of the seconds disc are symmetrical with the diaphragms marked on the prisms 34 and 28.

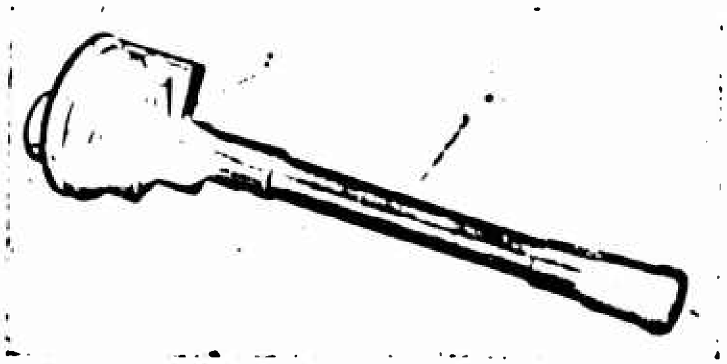

Fig. 20. Reading microscope and optical micrometer
1 - optical micrometer; 2 - special mounting; 3 - reading microscope in which the graticule is fitted.

After the illuminating prism has been set the seconds disc is set. The micrometer knob is turned to the stop and, observing in the reading microscope, the seconds disc is set so that the micrometer index is approximately half-way between the graduations numbered 0 and 60, after which the seconds disc is clamped. If the plane-parallel plates of the micrometer are parallel the readings on the seconds disc should be about 475.

(4) Testing the optical micrometer. The cam which drives the lever pins is made in the form of an Archimedean screw; as the cam is turned the angle of slope of the plane-parallel plates is altered.

The method of study proposed by engineer S.I. Ulichkin was to measure the angles of rotation of the plates as a function of the angle of rotation of the cam, using either a special fitting (Fig.21) which is a kind of goniometer, or else a precision goniometer.

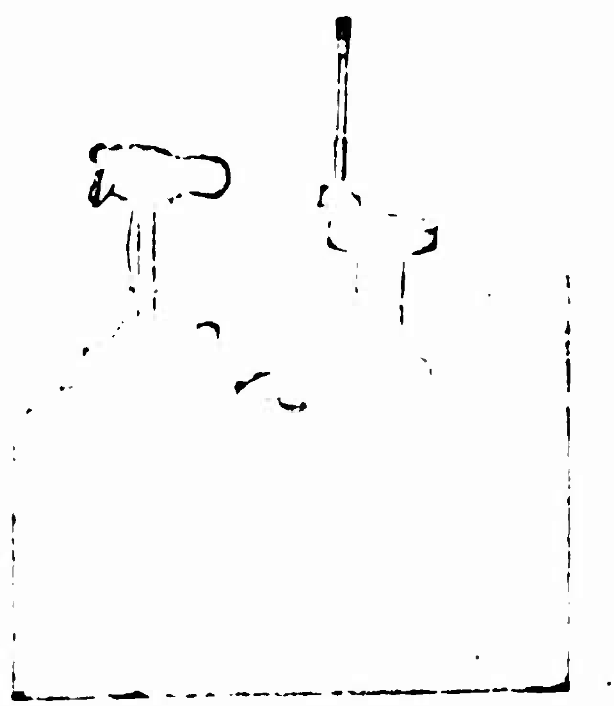

Fig. 21. Special device for inspecting the optical micrometer

The optical micrometer, which is connected to the reading microscope by a tube, is screwed onto a threaded upright on the stand. Observations are made through the reading microscope and the micrometer knob is turned, so moving the seconds disc and the cam that the driving pins move the levers and alter the slope of the plane-parallel plates of the micrometer.

Certain intervals are set on the seconds disc (Table 1) and the angles of rotation of the plates are measured, whilst observing in the autocollimation tube of the goniometer and reading from the dial microscope. Measurements of the increase in angle of rotation of the plates made in this way are compared with calculated values in Table 1.

Table 1

Calculated values of angles of rotation of the plates on different parts of the seconds disc

| Intervals on seconds disc | Rotation of plates |
|---|---|
| 0—50 | 0°27′47″ |
| 50—100 | 0 27 48 |
| 100—150 | 0 27 49 |
| 150—200 | 0 27 50 |
| 200—250 | 0 27 51 |
| 250—300 | 0 27 52 |
| 300—350 | 0 27 53 |
| 350—400 | 0 27 54 |
| 400—450 | 0 27 55 |
| 450—500 | 0 27 56 |
| 500—550 | 0 27 57 |
| 550—600 | 0 27 58 |

The measured angles should not differ from the calculated by more than one minute. If the difference is greater the micrometer may be corrected by adjusting the spring, by lapping the axes of the levers and the guide pins or by replacing the cam.

### 30. Fitting the prism of the reading microscope

Before fitting the prism of the reading microscope in the instrument it is necessary to check the mounting of the prism, because the base of the mounting should be parallel to the seating of the prism and perpendicular to the cylindrical generating line of the mounting. This condition is checked on a control plate by means of an indicating micrometer and an optical angle-measuring device. The prism is then fitted in its mounting and inserted into the telescope socket by means of a threaded mounting. An autocollimator is then set up alongside the instrument (Fig. 22).

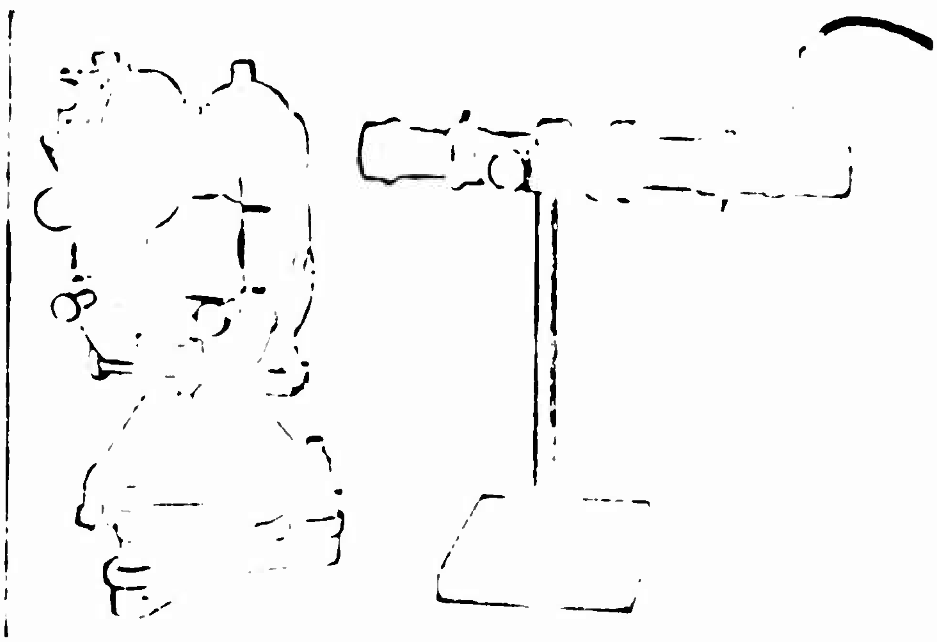

Fig. 22. Fitting prisms of the reading microscope

The prism is set in such a way that its inlet face is perpendicular to the axis of rotation of the telescope and the outlet face is symmetrical to the aperture for the tube of the reading microscope and perpendicular to its axis.

To do this the reading microscope is replaced by a tube to the end of which a plane-parallel plate is fixed. The prism and mounting are observed in the autocollimator and unscrewed until the light from the prism coincides with that from the plane-parallel plate. The tube is turned and the image of the light from the inlet face of the prism is observed in the autocollimator. If the prism is correctly set the position of the image should not alter when the tube is turned.

Correct setting of the reading microscope prism ensures that diametrically opposite graduations on the dials are uniformly illuminated and lie within the circle which is the image of the working diameter of the objective of the reading microscope. The illumination of the images of the disc graduations should be uniform over the entire field of vision with the tube in any position.

### 31. Adjustment of the optical system of the horizontal dial microscope

Adjustment of the horizontal dial microscope consists in adjusting the optical system of the microscope objective after the optical systems of the reading microscope and of the micrometer have already been adjusted. The objective of the horizontal dial microscope is first focussed so that the dial graduations appear sharp, by moving the objective in the alidade prism mounting using the screw mounting 1 (Fig.23) which is screwed into the mounting of the first component of the objective when the mounting holding the prism (24) has been removed (see Fig.3).

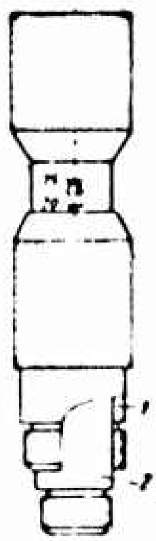

Fig. 23. Screw mandrel for preventing run
1 - outer casing; 2 - plunger.

When a sharp image of the dial graduations has been obtained, the alidade prisms are adjusted. The base plate and levelling screws are removed from the instrument and it is then fitted into a special wooden stand (Fig.24) and for convenience of adjustment a special fitting with reading microscope may be used (Fig.25,26).

Before adjusting them, the dimensions of the alidade prisms are checked, they are matched in pairs and the collimator with autocollimation eyepiece is used to check the accuracy of the cementing between the illuminator and alidade prisms. If the cementing has been done correctly the light from the flats of the illuminator prism 1[illegible] (see Fig.3) should coincide with that from the flats of the alidade prism 21.

After preliminary checking the alidade prisms are set in their mountings. If an old dial is replaced it may occur that the diameter of the graduations is greater on the new dial than on the old. It is then necessary to displace the alidade prisms during the adjustment but, meanwhile, light from the condenser 18 passes through the gap which is formed between them straight into the objective of the horizontal dial microscope. This causes diametrically opposite graduations of the dial to be differently illuminated and impairs their images. To correct this defect it is necessary to re-cement the alidade prisms and to lower the prisms somewhat so as to close the gap between the alidade prisms which are set in their mountings. The displacement of the alidade prisms along the mountings is observed in the reading microscope and they are set symmetrically about the axis of the objective of the horizontal dial microscope.

Here, the images of diametrically opposite graduations of the dial given by the dial microscope objective should be in the centre of the frame, visible in the reading microscope, and the graduations should be of equal height and perpendicular to the line of separation.

The base is then fixed to the carrier and the illuminating prism and condenser which are contained in a single holder are next fitted. This prism is adjusted to give uniform illumination of the

Fig. 24. Theodolite type OT-02 on a wooden stand

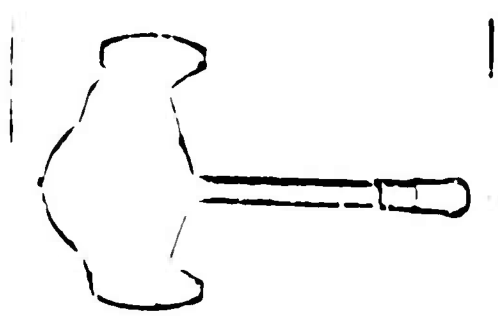

Fig. 25. Attachment to reading microscope for adjusting the vertical dial alidades

diametrically opposite graduations of the dial, and the quality of this illumination is checked with several dial diameters. The place at which the diametrically opposite graduations of the horizontal dial (for instance 0 - 180°) coincide is set relative to the micrometer index by displacing the swivelling prism 24 (see Fig.3) of the horizontal dial microscope.

Parallax between the images of the graduations of the dial is prevented by tilting one of the alidade prisms. To prevent parallax it is necessary to know the relationship between the change in the quantity x ( $\Delta x$ is the gap formed by the slope of the alidade prism in its mounting, see Fig.27) with change in the value of x', the amount of refocussing of the eyepiece, which for convenience is expressed in terms of the number of turns of the eyepiece mounting.

From the theory of the compound microscope it is known that (Fig.28)

$$x = \frac{f_{ob}^2}{\Delta_0}; \qquad x' = \frac{f_{ok}^2}{\Delta_0};$$

whence

$$\Delta_0 = \frac{f_{ob}^2}{x} = \frac{f_{ok}^2}{x'}. \qquad (11)$$

and

$$F_{micr} = \frac{f_{ob} \cdot f_{ok}}{\Delta_0},$$

where $F_{micr}$ is the focal length of the entire microscope system.

From formula (11) we have:

$$x' = \frac{f_{ok}^2}{f_{ob}^2} x. \qquad (12)$$

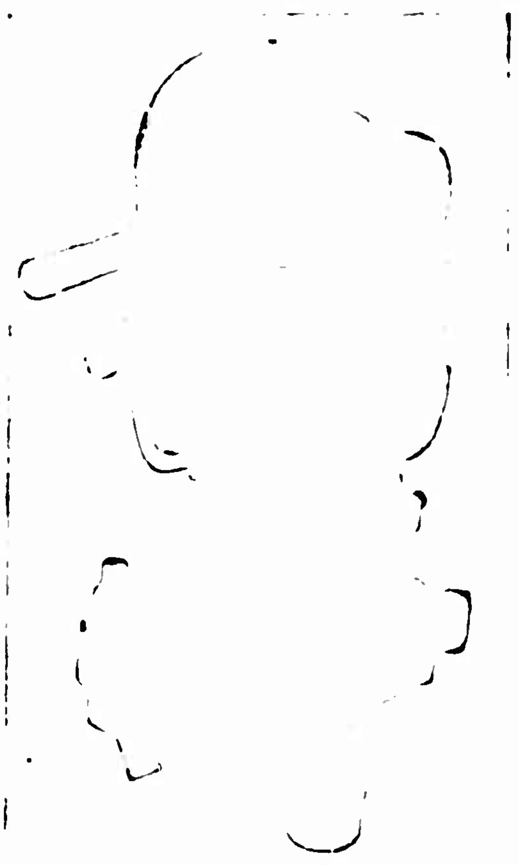

Fig. 26. Theodolite with device for adjusting the vertical dial alidades

Denoting the ratio $\frac{f_{ok}^2}{f_{ob}^2}$ by k and, differentiating formula (12), we obtain:

$$dx' = kdx. \tag{13}$$

From this formula we can determine the change in x' as a function of the change in x .

The amount of parallax can be expressed either in angular or in linear measure, but in the particular case of adjustment of the optical system of the compound microscope of theodolite OT-02 it is more convenient to express the parallax in terms of number of turns of the screw of the eyepiece mounting. If the pitch of the eyepiece mounting thread is denoted by s and the angle of rotation

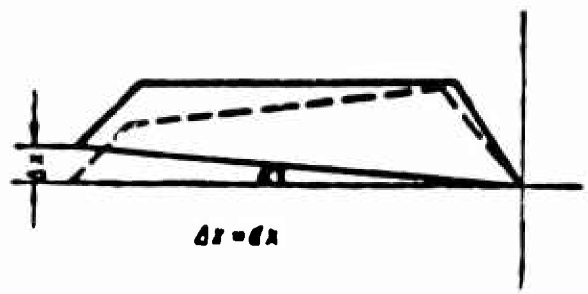

Fig. 27.

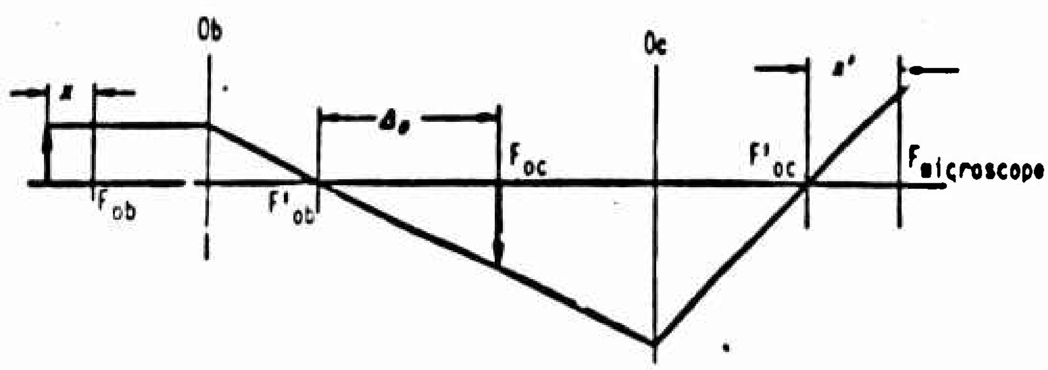


Fig. 28.
ob - objective; oc - ocular (eyepiece)

of the eyepiece mounting by $\varphi$ we may write down an expression between $d\varphi$ and $dx'$. For one revolution of the eyepiece frame the eyepiece is moved along the optical axis by a distance equal to the thread pitch $s$. Consequently,

$$dx' = ds.$$

Thus

$$d\varphi = \frac{dx' \cdot 360}{s}. \qquad (14)$$

Substituting the value of $dx'$ from formula (13) we have:

$$d\varphi = \frac{k \cdot 360}{s} dx. \qquad (15)$$

which gives the change in $x'$ expressed as turns of the eyepiece mounting, as function of change of $x$.

To avoid parallax in the horizontal and vertical dial microscopes of theodolite OT-02 it should be borne in mind that the tolerance for parallax between the images of diametrically opposite graduations of the dial should not exceed an eighth of a revolution of the eyepiece mounting. Beyond this it is necessary to correct parallax between images of dial graduations and the line of separation of the focussing objective of the horizontal dial microscope. Here, the parallax between images of dial graduations and the index of the optical micrometer, and also between the graduation of the seconds disc and the index, may be up to half the visible width of the graduation.

To prevent the adjustment from being disturbed the gaps between the alidade prisms and their mounting is filled with shellac.

Run in the horizontal dial microscope is corrected by altering the air gap between the components of the microscope objective. Since the images of the dial graduations should be sharp in checking the run when the air gap between the components of the objective is altered the position of the entire objective in the alidade prism mounting is altered at the same time by the correcting screw (see Fig.23).

The amount of run of the objective of the horizontal dial microscope should not exceed 3 divisions of the seconds disc. The presence of run indicates that the actual magnification of the microscope is not the same as the calculated value. To overcome this, when the number of divisions on the seconds disc is found to be more than 600,it is necessary to increase the distance between the components whilst displacing the images of the dial graduations by a single division, because this means that the microscope magnification is greater than calculated, and when the number of divisions is less than 600, the distance between the components of the microscope objective should be reduced, because this means that the microscope magnification is less than calculated.

In finally focussing the objective of the horizontal dial microscope for sharpness of image of the dial graduations, it is necessary to prevent parallax between the line of separation and the images of the dial graduations. After they have been finally adjusted, the mountings of the objective components of the horizontal dial microscope are secured with locking screws.

Determination of the influence of change in the distance between the components on magnification of the objective of the horizontal dial microscope of theodolite CT-02.

The cross magnification for a combination of two optical systems with a common axis is given by the following formula:*

$$\beta = \frac{f_1 f_2}{f_1 f_1' - x_1 \Delta} \qquad (16)$$

This formula can be written in the form:

$$\beta = \frac{-f_1 \cdot f_2'}{f_1'^2 - x_1 \Delta} \qquad (17)$$

Differentiating formula (17) and taking $\beta$ and $\Delta$ as variables and $x_1$ as constant we have:

$$\frac{d\beta}{d\Delta} = \frac{x_1 f_1' f_2'}{(f_1'^2 + x_1 \Delta)^2} \qquad (18)$$

Multiplying and dividing the right-hand side of formula (18) by $f_1' f_2'$ we obtain:

$$\frac{d\beta}{d\Delta} = \frac{x_1 f_1' f_2' f_1' f_2'}{(f_1'^2 + x_1 \Delta)^2 f_1' f_2'}$$

$$\frac{d\beta}{d\Delta} = \frac{x_1 \beta^2}{f_1' f_2'} \qquad (19)$$

$$d\beta = \frac{x_1 \beta^2}{f_1' f_2'}\, d\Delta$$

Since the quantities $\beta$, $f_1'$, $f_2'$ and $x_1$ are known for the given system, formula (19) may be written in the form:

$$d\beta = K\, d\Delta, \qquad (20)$$

where

$$K = \frac{x_1 \beta^2}{f_1' f_2'}.$$

---

* B.V. Fefilov. Applied Optics, Moscow, Geodezizdat, 1947

Let us determine the coefficient K (Fig.29). The objective of the horizontal dial microscope of theodolite OT-02 has: $f'_1$ = 82.820 mm , $f'_2$ = 121.613 mm, $x_1$ = 21.777 mm and $\beta$ = $4^x$, therefore,

$$K=\frac{x_1\beta^2}{f_1'f_2'}=\frac{21,777\cdot 16}{82,82\cdot 121,613}=0,0346.$$

$$d\beta=0,0346\cdot d\Delta. \qquad (21)$$

Since $d\Delta\approx dD_0$ , formula (21) may be written

$$d\beta=0,0346\,dD_0. \qquad (22)$$

Formula (22) can be used to determine the change in the magnification of the microscope objective with change in the distance between the components of the objective. Let us determine the change in magnification of the microscope objective expressed in divisions of the seconds disc of the optical micrometer. The half distance between graduations of the horizontal dial l = 0.039 mm , which corresponds to 120" angular measure. The seconds disc of the optical micrometer has 600 divisions and expressed in seconds each division corresponds to 0.2" in dial divisions,

$$t=\frac{0,2\cdot 0,039}{120}=0,000065 \text{ мм},$$

and in the plane of separating unit T = t x $\beta$ = 0.00026 mm .

The half distance between the graduations of the horizontal dial in this plane $l_1$ = l x $\beta$ = 0.039 $\beta$. Differentiating, we obtain: $dl_1$ = 0.039 d$\beta$ , and substituting the value of d$\beta$ we have

$$dl_1=0,039\cdot 0,0346\,dD_0,$$

but since $dl_1$ = T = 0.00026 mm , we have

$$dD_0=\frac{dl_1}{0,039\cdot 0,0346}=\frac{0,00026}{0,00136}=0,2 \text{ мм}.$$

Consequently, changing the distance between components of the horizontal dial microscope objective by an amount of 0.2 mm causes a change in the run of about 1 division of the seconds disc of the optical micrometer.

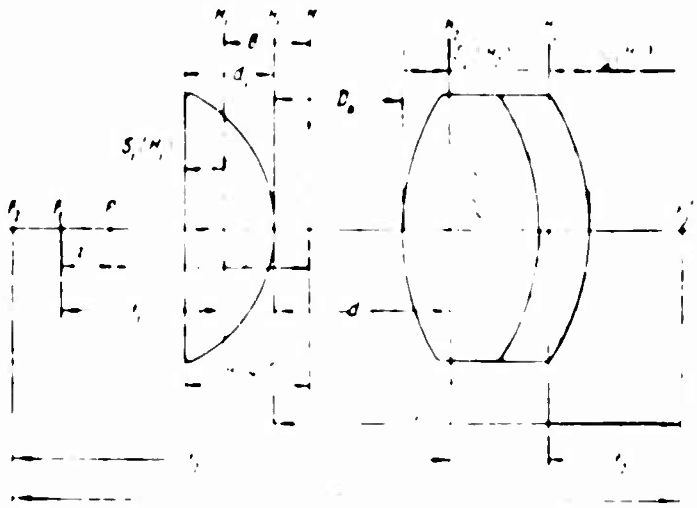

Fig. 79. Diagram of horizontal dial microscope objective

### 32. Checking that the horizontal axis of the theodolite is perpendicular to its vertical axis

Finally, the assembled instrument is set up on a suitable base, and a plumb line is set up 10 - 15 m from the instrument. The instrument is first set to the level of the horizontal dial alidade so bringing the vertical axis to the plummet position. The telescope is then aimed at the top of the plumb line until the cross in the graticule coincides with the plumb line. The telescope is then traversed downwards along the plumb line and it is observed whether the graticule and plumb lines cross. If they do, the screws which fix the carrier to the stand are slackened and the upper part of the theodolite is removed. Then, depending upon the slope of the horizontal axis, one of the stand uprights is corrected by scraping. The angle between the horizontal and vertical axes of the theodolite should be perpendicular to within 5 seconds.

A more accurate check can be made with two or three collimators which are fixed by brackets to a wall or to a concrete column. The collimators are set in such a way that the hair line intersections meet on a single straight plumb line. With this method, the check can be made with the telescope sloping at a much greater angle.

## 33. Adjustment of the optical system of the vertical dial microscope

The adjustment of the optical system of the vertical dial microscope consists in fitting the optical system into the microscope objective. First the swivelling prism 12 and the selector prism 15 (see Fig.3) are fitted. Then a plane-parallel plate is placed in the plane of the stand upright at the position where the micrometer bearing is located. The swivelling prism 12 is observed through the autocollimator and the prism is set so that the light from the plane-parallel plate of the selector and swivelling prisms coincide. After this the bearings, the vertical turntable housing, the dial and the alidade are fitted and also a special device is fitted to the reading microscope (Fig.26 ). This device has seating diameters equal to the diameter of the telescope socket. When it is connected to the vertical turntable housing, it forms a window through which the alidade prism can be adjusted.

Before the alidade prisms are adjusted the vertical dial microscope objective is focussed to give a sharp image of the dial graduations. This is achieved by shifting the first component of the objective which is located in the mounting of the alidade prism of the vertical turntable by means of a special screw which is screwed through the mounting of the alidade prisms into the objective mounting.

When a sharp image of the graduations of the vertical dial has been obtained the alidade prisms 10 (see Fig.3) are adjusted. Before the alidade prisms are adjusted they are measured and matched in pairs and an autocollimator is used to check the correctness of the cementing between the illuminating prism and the alidade prism. The alidade prisms are then temporarily fitted in their mounting.

For convenience of adjustment the instrument is placed on a special wooden stand (Fig.30). Observing through the reading microscope, the alidade prisms are moved along the carrier until they are symmetrical about the axis of the vertical dial microscope objective.

Then the images of diametrically opposite dial graduations given by the vertical dial microscope objective should be in the middle of the diaphragm visible in the reading microscope, and the graduations should be of equal height and perpendicular to the line of separation.

The lighting system of the vertical dial microscope objective is adjusted by moving the prisms 5 and 6 (see Fig.3) which are lit by an electric lamp in a special housing fixed to the alidade prism mounting. The illumination of diametrically opposite graduations should remain equal and uniform when the slope of the telescope is altered.

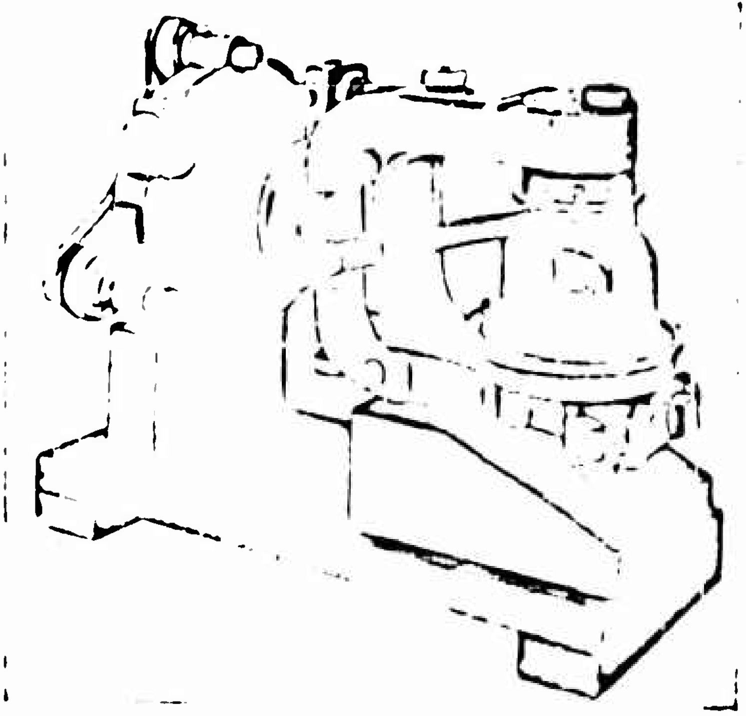

Fig. 30. Theodolite without telescope on special stand

Parallax between the images of opposite graduations of the vertical dial is corrected by tilting one of the alidade prisms. Here, the same conditions should be fulfilled as in adjusting the optical system of the objective of the horizontal dial microscope.

The run of the vertical dial microscope is corrected by altering the air gap between the components of the microscope objective by moving the second component which is in the left-hand upright of the stand and the first component which is within the mounting of the vertical dial alidade prisms. The magnitude of the run on the objective of the vertical dial microscope should not exceed 3 divisions of the seconds disc.

Run should be prevented by following the guidance given above. After adjustment, the gaps between the alidade prisms and their mountings are filled with shellac and the mountings of the components of the objectives of the vertical dial microscope are secured with locking screws.

### 34. Fitting of the dioptric ring

In setting the dioptric telescope to zero the telescope graticule is observed through the eyepiece. The eyepiece is focussed to give a sharp image of the graticule; the zero graduation of the dioptric ring is then made to coincide with the pointer index and the dioptric ring is locked.

The correctness of setting of the dioptric ring is checked by means of a dioptric telescope set for dioptry of ±5. Here, the image of the telescope graticule should be uniformly sharp and distinct.

### 35. Fitting of graticule

The instrument is levelled on its stand and a plumb line is set up 10-15 metres distant from the instrument. The telescope is aligned on the plumb line and the graticule is set on it.

*

* *

During the process of adjustment and during final assembly steel parts are covered with special lubricants and coatings to prevent corrosion.

After final assembly, to seal the instrument hermetically, gaps at joints between the parts are filled with a special compound, using an electric soldering iron.

## 36. Study of aberrations in the telescope optical system

Determination of the telescope resolving power by the method described above and of the quality of centering of the objective system by an illuminated point in the collimator focus does not give a full understanding of the optical properties of the system. In Class 1 triangulation work it is necessary to observe stations at distances of 25 km and more and, therefore, the optical system of the sight tube should be of very high quality.

Defects in optical systems result from inadequate finishing of the surfaces, from variations in the glass, from the influence of the spherical shape of the surfaces and also because the light is not monochromatic.

By way of example, we describe an examination of the telescope aberrations in a Wild T3 optical theodolite which was made by Engineer B.S. Grishin and Candidate of technical sciences V.A. Afanas'ev in 1940. The tests were made by the GOI method, using a Hartman bench with a telescope objective focal length of 90[illegible].69 mm.

The GOI method is an improved visual Hartman method, which is based on using the phenomenon of interference from diffracted light formed by a narrow slot. Here the interference plays an auxiliary part and helps to locate more accurately the focus of the optical system of the objective under test. Unlike Veyzel's method (in which two apertures are used) the GOI method uses a diaphragm with two pairs of apertures located symmetrically relative to the centre of the collimator objective.

Testing an objective by the GOI method consists in focussing the interference bands of light from the corresponding zones of the objective system which is being tested. The procedure for examination of the telescope system for aberrations is as follows: the telescope optical system was first examined for aberration, then the objective, after which the mounting with the actual objective (the three front lenses) was unscrewed and the objective itself examined.

Spherical and chromatic aberration and axial astigmatism were examined. Before the examination a slot diaphragm was installed on the collimator axis of the optical bench. A diagram of this slot is given in Fig.31, where S is a strong source of light (such as a point-source lamp), K a condenser, Φ a filter, $D_1$ is a slot diaphragm, Ok a test system eyepiece, $O_1$ the objective of the system under test, $D_2$ a zonal diaphragm, $O_2$ the objective of the bench collimator and F the focus.

Fig. 31. Diagram of setting of telescope test system

Then a collimator was fitted to the telescope system under test in such a way that the diaphragm slot was in the outlet iris (the telescope under test was focussed to infinity). A special zonal diaphragm was mounted on the bench telescope (Figs.32,33). This diaphragm is simple in construction and convenient in use, on its body there is a gap 25 mm wide and a pointer (Fig.33). Secured to the diaphragm frame is a disc in which holes are drilled 1 mm in diameter and 2.5 mm apart. Pairs of holes are arranged in an Archimedean spiral (Fig.32): the disc also has numbered points which indicate the number of the zone. By rotating the disc two pairs of holes in any zone can be opened. Fig.32 shows that zone 6 coincides with the index of the diaphragm and Fig.33 shows two pairs of holes coincide with the slot.

The bench telescope (collimator) has a removable eyepiece on which divisions are marked. There is a vernier on the telescope frame. In examining the telescope objective the diaphragm slot is set in the focus of the test objective.

The process of measuring aberration is as follows:

1. Two pairs of holes of the corresponding zone are opened in the zonal diaphragm.

2. The interference bands are made to coincide by observing through the optical bench telescope and operating the rack of the eyepiece part of the telescope. Fig.34 shows the field of vision of the bench telescope (collimator) at the instant of opening the aperture of the next zone. Fig.35 shows it at the instant when the interference bands coincide.

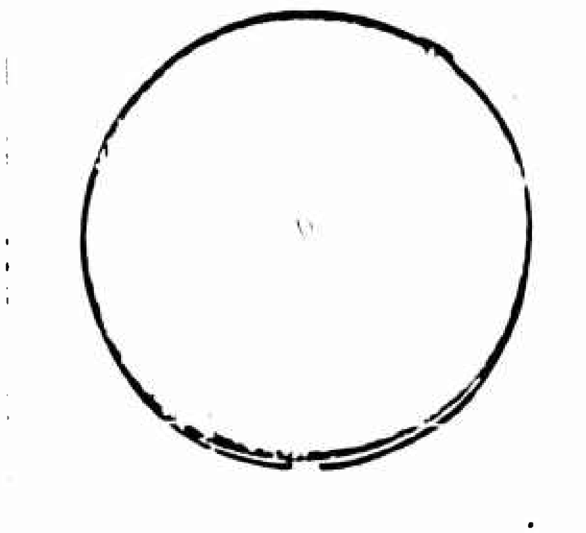

Fig. 32. Zonal diaphragm (front view)

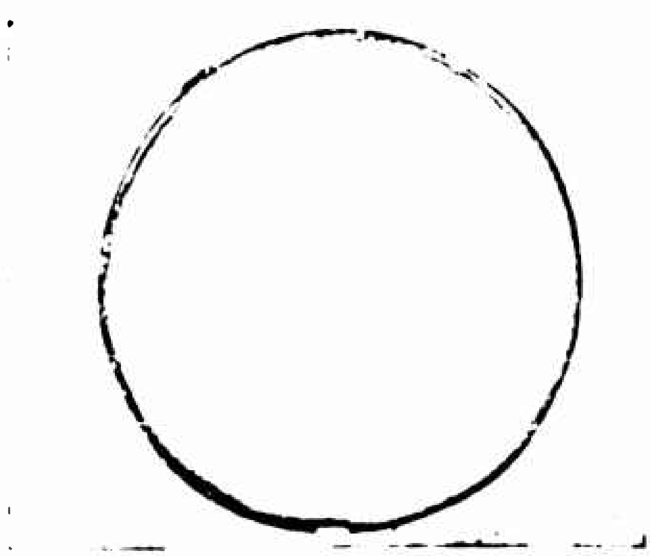

Fig. 33. Zonal diaphragm (rear view)

3. After the interference bands have been made to coincide a reading is taken on the optical bench telescope vernier.

Examinations were made on 7 zones every 4 mm because the free aperture of the telescope objective under test was 60 mm.

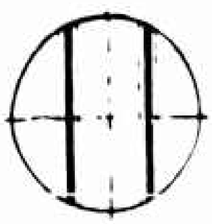

Fig. 34. Field of vision of collimator at instant of opening hole in the next zone of the zonal diaphragm

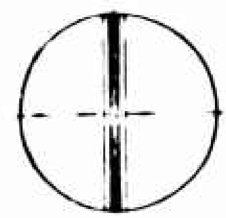

Fig. 35. Field of vision of collimator at instant when interference bands coincide

Five readings were taken in each zone. To determine the chromatic aberration the measurements were made with various filters (yellow, red and green). Astigmatism on the axis was measured with a yellow filter and when the slot was vertical the holes in the zonal diaphragm were horizontal and when the slot was horizontal the holes in the zonal diaphragm were vertical, i.e. the zonal diaphragm turned through 90° in a plane perpendicular to the collimator axis. All the data of the examination are presented in the form of tables and graphs of aberration*.

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* For working out the results of aberration investigations on optical systems see the book by V.A. Afanas'ev 'Practical Applied Optics' (Praktikum po prikladnoy optike), Geodezizdat, Moscow, 1941, p.103.

The aberration coefficient $\delta S'_n$ was calculated by the formula

$$\delta S_n' = A_0 \left(\frac{f}{F}\right)^2. \tag{23}$$

where $A_0$ is the reading on the collimator vernier (mean of five), $f$ is the focal length of the system under test, $F$ is the focal length of the bench collimator. Since the focal length of the collimator is known ($F = 909.69$ mm) we obtain:

$$\delta S_n' = A_0 \left(\frac{f}{909.69}\right)^2. \tag{24}$$

The results of aberration determinations are given in Tables 2, 3, 4, 5, 6, 7 and 8.

From the tables and figures, it will be seen that the aberration of the actual objective is much less than that of the telescope as a whole. Analysis indicates that:

1. The aberration of the actual objective does not exceed the tolerance limit.

2. The telescope objective has chromatic aberration somewhat exceeding the tolerance limit; the spherical aberration and astigmatism are within tolerance.

3. The telescope as a whole has considerable chromatic aberration.

Astigmatism on the axis is insignificant and is of the order of the error of measurement.

Table 2

Results of measurements of sperical aberration
of the actual telescope (Fig. 36.)

| Filter / Zone mm | Red λ = 640 | | Yellow λ = 586 | | Blue λ = 434 | |
|---|---|---|---|---|---|---|
| | $A_0$ | $\delta S'_h$ | $A_0$ | $\delta S'_h$ | $A_0$ | $\delta S'_h$ |
| 4 | 368,2 | 4,49 | 363,0 | 3,72 | 367,3 | 4,36 |
| 6 | 368,4 | 4,52 | 364,3 | 3,91 | 367,7 | 4,42 |
| 10 | 368,2 | 4,49 | 364,3 | 3,91 | 368,0 | 4,46 |
| 14 | 368,1 | 4,48 | 363,9 | 3,86 | 367,5 | 4,39 |
| 18 | 368,3 | 4,51 | 364,2 | 3,90 | 368,3 | 4,51 |
| 22 | 368,4 | 4,52 | 364,8 | 3,99 | 370,0 | 4,76 |
| 26 | 369,2 | 4,64 | 365,7 | 4,12 | 371,6 | 5,00 |

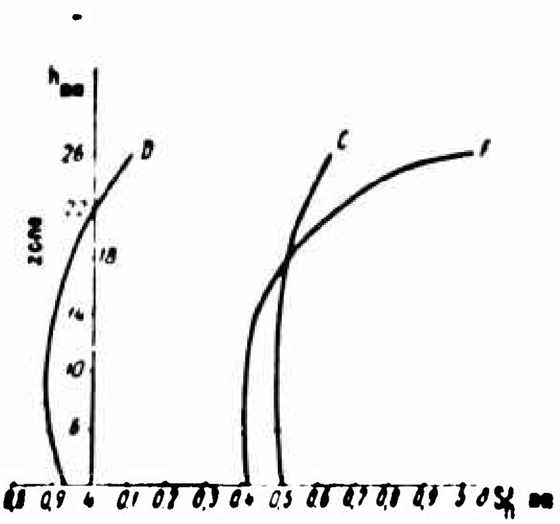



Fig. 36. Graph of spherical aberration of the actual telescope

Table 3

Results of astigmatism measurements on the axis of the actual telescope (Fig. 37.)

| Zone № \ Slot position | Vertical | | Horizontal | | Astigmatism on the axis |
|---|---|---|---|---|---|
| | $A_v$ | $\delta S'_{A_0}$ | $A_e$ | $\delta S'_{A_{90}}$ | $A=\delta S'_{A_0}-\delta S'_{A_{90}}$ |
| 4 | 364,9 | 4,00 | 365,3 | 4,06 | −0,06 |
| 6 | 366,8 | 4.28 | 366,1 | 4,18 | +0,10 |
| 10 | 366,1 | 4,18 | 365,1 | 4,03 | +0,15 |
| 14 | 365,1 | 4,03 | 365,1 | 4,03 | 0,00 |
| 18 | 365,1 | 4,03 | 365,0 | 4,02 | +0,01 |
| 22 | 365,6 | 4,10 | 364,4 | 3,93 | +0,17 |
| 26 | 366,5 | 4,24 | 365,2 | 4,05 | +0,19 |

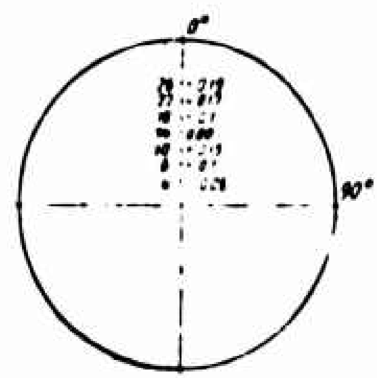



Fig. 37. Graph of astigmatism on the axis of the actual telescope

Table 4

Results of spherical aberration determinations on the telescope objective (Fig. 38)

| Zone mm \ Filter | Red $\lambda = 640$ | | Yellow $\lambda = 586$ | | Blue $\lambda = 434$ | |
|---|---|---|---|---|---|---|
| | $A_0$ | $\delta S'_h$ | $A_0$ | $\delta S'_h$ | $A_0$ | $\delta S'_h$ |
| 4 | 331,1 | 9,00 | 327,6 | 8,48 | 329,5 | 8,77 |
| 6 | 331,9 | 9,12 | 328,9 | 8,68 | 330,1 | 8,85 |
| 10 | 330,4 | 8,90 | 328,1 | 8,56 | 330,4 | 8,90 |
| 14 | 332,1 | 9,15 | 327,8 | 8,51 | 330,6 | 8,93 |
| 18 | 330,6 | 8,91 | 328,2 | 8,57 | 330,4 | 8,90 |
| 22 | 331,2 | 9,02 | 328,7 | 8,65 | 331,7 | 9,09 |
| 26 | 330,2 | 8,87 | 329,7 | 8,79 | 333,0 | 9,28 |

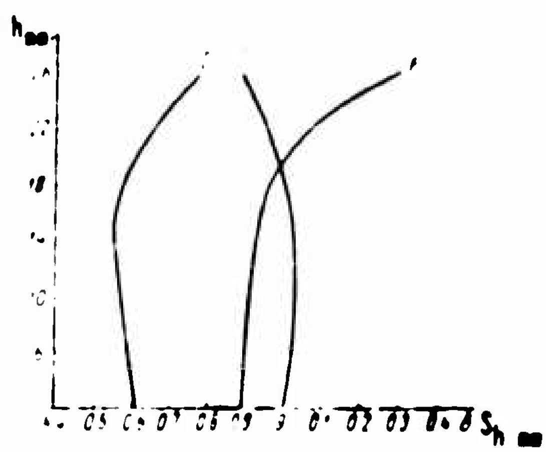



Fig. 38. Graph of spherical aberration of the telescope objective

Table 5

**Results of astigmatism measurements on the axis of the tube objective (Fig. 39.)**

| Slot position / Zone mm | Vertical | | Horizontal | | Astigmatism |
|---|---|---|---|---|---|
| | $A_0$ | $\delta S'_{h_0}$ | $A_0$ | $\delta S'_{h_{90}}$ | $A-\delta S'_{h_0}-\delta S'_{h_{90}}$ |
| 4 | 327,6 | 8,48 | 327,5 | 8,47 | +0,01 |
| 6 | 328,9 | 8,68 | 328,1 | 8,56 | +0,12 |
| 10 | 328,1 | 8,56 | 327,8 | 8,51 | +0,05 |
| 14 | 327,8 | 8,51 | 327,9 | 8,53 | −0,02 |
| 18 | 328,2 | 8,57 | 328,0 | 8,54 | +0,03 |
| 22 | 328,7 | 8,65 | 328,4 | 8,60 | +0,05 |
| 26 | 329,7 | 8,79 | 329,2 | 8,72 | +0,07 |

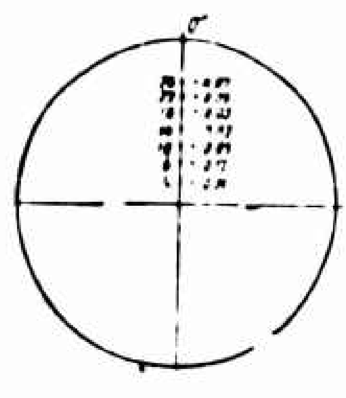


Fig. 39. Graph of astigmatism on the axis of the telescope objective

Table 6

Results of spherical aberration measurements of the actual objective (Fig. 40)

| Filter / Zone mm | Red $\lambda = 640$ | Yellow $\lambda = 586$ | Blue $\lambda = 434$ |
|---|---|---|---|
| | $\delta S'_h$ | $\delta S'_h$ | $\delta S'_h$ |
| 4 | 6,207 | 6,034 | 6,291 |
| 6 | 6,377 | 6,519 | 6,497 |
| 10 | 6,604 | 6,523 | 6,465 |
| 14 | 6,539 | 6,646 | 6,488 |
| 18 | 6,589 | 6,608 | 6,487 |
| 22 | 6,514 | 6,581 | 6,428 |
| 26 | 6.523 | 6,617 | 6,448 |

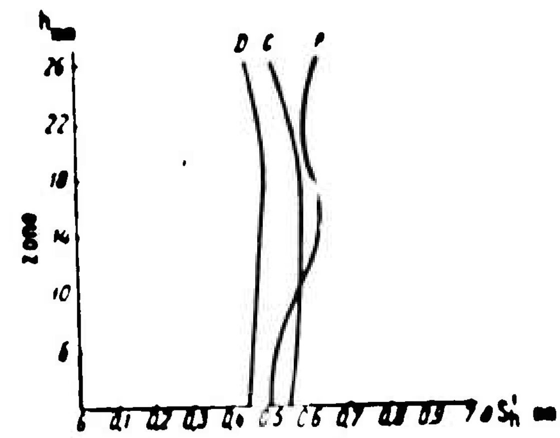



Fig. 40. Graph of spherical aberration of the actual objective

Table 7

Results of astigmatism measurements on the axis of the actual objective (Fig. 41.)

| Slot position / Zone mm | Vertical $\delta S'_{h_0}$ | Horizontal $\delta S'_{h_{90}}$ | Astigmatism on the axis $A = \delta S'_{h_0} - \delta S'_{h_{90}}$ |
|---|---|---|---|
| 4 | 6,29 | 6,31 | −0,02 |
| 6 | 6.50 | 6,45 | +0,05 |
| 10 | 6,46 | 6,48 | −0,02 |
| 14 | 6,49 | 6,51 | −0,02 |
| 18 | 6,49 | 6,51 | −0,02 |
| 22 | 6,42 | 6,46 | −0,04 |
| 26 | 6,45 | 6,42 | +0,03 |

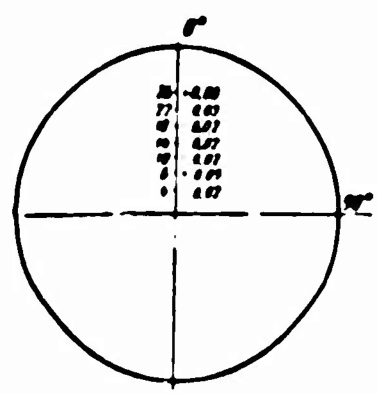



Fig. 41. Graph of astigmatism on the axis of the actual objective

Table 8

Summary table of chromatic aberration measurements on the axis of the actual objective (for h = 22 mm, Figs. 42, 43 and 44.)

| Colour (wavelength) | Actual tube | Objective | Actual objective |
|---|---|---|---|
| $C$ ($\lambda = 640$) | 4,52 | 9,02 | 6,51 |
| $D$ ($\lambda = 586$) | 3,99 | 8,65 | 6,43 |
| $F$ ($\lambda = 434$) | 4,76 | 9,09 | 6,58 |

Fig. 42. Graph of chromatic aberration of the actual telescope

Fig. 42. Graph of chromatic aberration of the actual telescope for h = 22 mm

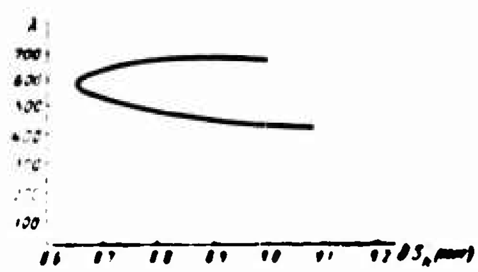


Fig. 43. Graph of chromatic aberration of the telescope objective for h = 22 mm

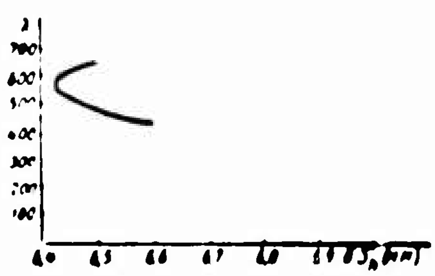


Fig. 44. Graph of chromatic aberration of the actual objective for h = 22 mm

Examination for aberration of telescopes of an optical theodolite, as of any other telescopic system, is of pressing importance, particularly when the optical parts of the tube are made from glass in which there are small deviations from the technical standards and also when examining the advantages of one system as compared with another. Finally, investigation of the aberrations of an optical telescope system is very important in developing prototypes because it provides a basis for improving quality.

## Chapter 5

# CLEANING, LUBRICATION, MINOR ADJUSTMENTS AND PROCEDURE FOR REPLACING INDIVIDUAL COMPONENTS

### 37. Cleaning lens, prisms, and seconds disc

The following material and instruments are required to clean the optical parts: 96% ethanol, ether, aviation gasoline, hygroscopic cotton wool, sharpened sticks of wood, hand towels of fine linen, camel-hair brushes, a rubber bulb, forceps, a watchmaker's screwdriver, wooden tongues for unscrewing the mounting of the telescope objective, a 10 x magnifying glass.

The lenses of the theodolite optical system are cleaned in various ways. Lenses which are not secured in the mounting are cleaned by hand. Uncemented lenses are cleaned with cotton wool wetted with ethanol, after which they are dried with a cloth. Then the lens is held in the forceps and the dust is blown off with the rubber bulb, and what remains is removed with a camel-hair brush.

When cleaning cemented lenses it is important to ensure that the spirit does not get between the lenses and damage the cement. Cemented lenses are cleaned in the same way as uncemented.

When cleaning lenses of the telescope objective and eyepieces the spacer rings should also be cleaned. The spacer rings are first washed in aviation gasoline and are then carefully wiped with a cloth. To remove fluff from a spacer ring it is dipped in ether and immediately after removal it is burned.

Uncemented prisms are washed in spirit and dried with a cloth. The prism is then picked up with the forceps on the ground surfaces and dust is blown off with the rubber bulb. The remaining pieces of dust are removed with the camel-hair brush. In cleaning cemented prisms, for example the separating unit, particular care must be taken and the cotton wool must be only lightly moistened with spirit without wetting the cementing.

The telescope graticule is cleaned with cotton wool moistened with spirit, taking care that the spirit does not get into the cementing.

It is particularly difficult to clean the seconds disc 34 the illuminating prism and the prism which transmits the image of the dial graduations 28. It is not recommended to use ethanol to clean these parts because the spirit removes the paint which is used to fill the graduations of the seconds disc and the diaphragm of the prisms. In this case the cotton wool is lightly moistened with pure gasoline. After the part has been cleaned it should be wiped with cotton wool attached to a stick, the remaining fluff is removed with a camel-hair brush.

The following conditions apply in cleaning optical parts:

1. The room in which the cleaning is carried out should be dust-free;

2. the room should be sufficiently dry, there should be no sudden changes in temperature, because these can cause deposits to form on the surfaces of optical parts;

3. the operator must have clean hands.

## 38. Lubrication of components and assemblies

Both the vertical and the horizontal axial systems of an optical theodolite are lubricated with special watch oil with a specific gravity of 0.900, neutralisation value less than 0.11 mg KOH/g, viscosity of $4.27^{\circ}$ Engler at $35^{\circ}C$ and the pour point about $-26^{\circ}C$.

Before lubricating the vertical axis the vertical axis main bearing, the bearings and all the other parts of the vertical and horizontal axes are carefully washed in aviation gasoline and then dried.

The parts are protected against oxidation and water absorption by a compound of the following composition in percentage by weight: soap 5, high melting point ceresine 5, aviation engine oil 42.5, bore oil 42.5, and natural wax 5. This compound is applied to the following parts of the optical theodolite: the outer surfaces of the dial bush, the split ring, the clamping sleeve of the horizontal dial alidade, the clamping nut, the mounting for the level bulb of the horizontal dial alidade, the wall of the right-hand upright of the stand on the selector prism side, the housing of the vertical dial alidade level, the cover of the objective knob at the place where it fits with the mounting of the actual objective, the telescope cover at places where it fits with the telescope, the outside of the mounting of the focussing lenses, and the inner surfaces of the bearings.

The compound which is applied to components which are remote from the optical parts is of the following composition in percentage by weight: high melting point ceresine 26, vaseline oil 55, lanoline 3, natural wax 11, ozokerite 5. This compound is applied to: the mounting of the alidade prisms of the dial and of the vertical dial, the carrier base (inner surface), the mounting of the swivelling prism, the horizontal dial, components of the optical micrometer, the mounting of the actual objective, the telescope frame, the graticule mounting, the inner surface of the telescope socket (except the seating place of the micrometer bearing) the inner surface of the vertical turntable housing (except where the turntable seats).

The seating places of the horizontal dials on the dial sleeve, of the vertical dial on the vertical turntable housing, the alidade prisms and the spacer rings between the objectives in the telescope are wiped with a cloth soaked in the lubricant used for components close to the optical parts.

To ensure that the instrument is hermetically sealed all the components which cover up ingress to the instrument must be coated after final adjustment. The compound used for this purpose has the following percentage composition by weight: ozokerite 55, technical vaseline (petrolatum) 25, gum rosin 20; alternatively the following composition may be used: high melting point ceresine 31.5, beeswax 30.4, technical vaseline (petrolatum) 14.7, gum rosin 21.5, caster oil 1.9. Both these compounds are fairly hard and solid and, therefore, they are applied to the gaps between parts with an electric soldering iron. In the optical theodolite OT-02 the joints between the following adjoining parts are treated in this way. In the lower part of the theodolite, between the carrier and its base, the carrier base and the mounting of the dial illuminating prism, the gear block and the carrier. In the central part of the theodolite, between: the cover of the selector and the support, the mounting of the swivelling prism of the vertical dial and the support, the mounting of the cover glass and the right-hand wall of the support, the mounting of the second component of the objective of the vertical dial microscope and the stand. In the upper part of the theodolite between the telescope covers and the telescope socket and between the objective know cover and the mounting of the actual objective, be ween the mounting of the micrometer and the micrometer bearing, between the turntable bearing and the micrometer bearing in the stand.

### 30. The correction of defects in the axial systems

Before considering the correction of defects in the axial systems of the theodolite we shall discuss the procedure for dismantling the principal components of the instrument, particularly the lower and upper parts.

<u>Procedure for dismantling the lower part of the theodolite</u>

First unscrew the locking screw 27 which fixes the seating of the horizontal dial alidade prisms to the stand (Fig.45). Then unscrew the locking screws from the nuts which fix the levelling screws to the carrier after which unscrew these nuts with a special spanner. Place the instrument upside down in a special wooden stand (see Fig.24); remove the base plate together with the levelling screws; disconnect the electrical conductors from the socket on the base of the carrier; unscrew the screws which fix the base to the carrier and remove it; carefully withdraw the carrier with the alidade prisms whilst avoiding touching the prisms by hand; separate the conductor with the sliding contact 8 (see Fig.1)from the block; unscrew the catch from the alidade clamp; lightly turn the carrier, lift it and remove it from the axis (taking care that the balls do not fall out); unscrew the three screws that fix the catch sleeve to the carrier; unscrew the catch sleeve together with the catch.

If the lower part of the theodolite is dismantled for lubrication the clamp is not dismantled but the catch which fixes the nut to the clamp sleeve is unscrewed. Undo the nut and remove the horizontal dial alidade clamp of the horizontal dial. In assembling the clamp with its sleeve take care to get the brake block in its previous position.

Next unscrew the four screws which join the two half-rings to the vertical axis main bearing and the dial sleeve to the carrier. It is recommended to mark the vertical axis main bearing and the half-rings so that they can be placed in the same position on re-assembly. In dismantling this assembly take particular care with the dial sleeve to ensure that the dial setting is not disturbed, particularly when it is not intended to reset it. If the dial eccentricity exceeds 10 seconds, it is necessary to set the dial by the procedure described above.

GRAPHIC NOT REPRODUCIBLE

Fig. 45. Theodolite type OT-02

27 - lock for horizontal dial alidade prism mounting; 28 - telescope socket; 29 - turntable bearing; 30 - clamp for level of vertical dial alidade; 31 - contact ring; 32 - plug socket for electricity supply.

Assemble the lower part of the theodolite in the reverse order to that of dismantling.

<u>Procedure for dismantling the upper part of the theodolite</u>

Unscrew the lock of the telescope sighting adjustment screw and then unscrew the adjustment screw itself; undo the screws which secure the clamp cover plate and remove it; undo the four screws which secure to the base the plate which carries the selector prism mechanism and remove it.

Undo the two screws which fix the micrometer bearing to the right-hand upright of the stand and the six screws which fix the telescope socket to the vertical turntable noting the mutual location of the parts with a light mark. Set the telescope and clamp approximately horizontally.

Then take the micrometer bearing and the telescope socket with the telescope in both hands without separating them and move them along the plane of the right-hand upright, withdraw the joint between them from the vertical turntable housing and remove them from the instrument. This operation must be carried out with great care and without bending so that breaking of the vertical dial alidade prisms is avoided. Whilst the operation is being performed use only one hand to hold the micrometer bearing close to the telescope socket.

Carefully separate the micrometer bearing from the telescope socket. In correcting defects in the horizontal axis system, if there are no traces of strain on the bearing, or scratches or the like, it is not necessary to withdraw the optical micrometer from the bearing, but cover the hole to prevent ingress of dust, also clean and lubricate the equipment.

Unscrew the lock from the clamp nut, remove the nut itself and remove the telescope clamp together with the telescope socket.

Unscrew the lock of the level adjusting screw and undo the screw itself.

Undo the three reinforcing screws and also one contact screw on the bush of the vertical dial illuminator. In undoing these screws press the alidade prisms mounting lightly against the turntable seating from the side of the turntable housing.

Hold the mounting of the vertical turntable alidade in the left hand and remove the clamp from the vertical dial alidade level.

Undo two screws which secure the support to the base under the mounting of the swivelling prism of the vertical dial microscope and remove the support.

Release the two adjusting screws and withdraw the mounting with the swivelling prism from the stand socket.

Carefully withdraw the mounting with the alidade prisms. In doing this it is necessary to hold the wires with the contact screw. Remove the vertical turntable housing from its bearing; unless it is essential to do so, do not remove the turntable bearing from the stand because its position in the stand affects the adjustment of the horizontal and vertical dial microscopes.

Assemble the upper part in the reverse order to that of dismantling.

<u>Defects in the axial systems of the theodolite</u>

1. Difficulty in rotation about the vertical axis.
2. Difficulty in turning the telescope.
3. Jamming in the horizontal axis system.

Difficulty in turning the axis systems, which have small clearance of the order of 0.0015 mm, is generally due to thickening of the watch-oil. This is corrected by replacing the oil. To do this, dismantle the instrument, remove the old lubricant from the components of the axial system, and wipe them carefully with a cloth moistened with aviation gasoline and then again lubricate them with watch oil. Then assemble the theodolite and adjust it. The components of the horizontal axis system must be cleaned and lubricated with particular care because optical components are present in the bearings and the telescope socket.

Jamming of the horizontal axis system of the instrument usually results from displacement of the bearings (misalignment) by mechanical shock in transportation. Consequently, the telescope will not turn and a crossed image of the dial graduations is seen in the field of vision of the reading microscope. Take the following steps if one micrometer bearing has been displaced. Slacken off by two or three turns the screws which fix the micrometer bearing to the stand. Look through the reading microscope and move the micrometer bearing in the support plane on the stand until the images of the dial graduations are correct and at the same time the telescope turns freely about the horizontal axis. Then secure the micrometer bearing.

If both bearings have been displaced, again slacken their holding screws by two or three turns, press both bearings by hand towards the telescope socket and the vertical turntable housing and displace the entire system of the upper part of the instrument on the support plane of the stand until the images of the dial graduations are correctly located in the reading microscope and the telescope turns freely. Then carefully tighten the screws which secure the turntable bearing to the stand. Press the micrometer bearing towards the telescope socket and observe in the reading microscope whether there has been any displacement. If there has not, then secure the micrometer bearing.

In setting the turntable and micrometer bearings the micrometer index may become displaced relative to the place where the diametrically opposite graduations coincide, for example, 90 - 90°. To correct this, unscrew the swivelling prism of the vertical dial microscope with the adjusting screws. Then the place where the diametrically opposite graduations of the horizontal dial coincide, for instance, 0 - 180°, should simultaneously coincide with the micrometer index.

When diametrically opposite graduations coincide at the position of the micrometer index, check the general adjustment of the instrument, i.e. check the collimation error, the setting of the zenith, etc.

## 40. Repair of the optical micrometer

The optical micrometer may have various defects which call for adjustment or replacement of components. The former are corrected by the procedures described above, and for the latter, spare parts are required.

To correct the micrometer remove it from the instrument, first undoing the screws which secure the micrometer to the bearing, then examine the fixings of the lever springs and the springs themselves.

The optical micrometer is dismantled as follows. Undo the micrometer head lock, remove it from the cam shaft; undo the screw which secures the cam to the cam shaft and withdraw the cam shaft from the seconds disc. Then undo the screws which secure the micrometer bridge to the micrometer mounting and, freeing the lever springs remove the micrometer bridge.

Further, undo the screws which secure the lever bridge to the micrometer mounting, remove it from the mounting and then remove the levers and cams; examine the lever guide pins. If these have been bent or damaged replace them with new ones made of steel grade U7A or U8A hardened to $R_c$ = 40 - 45.

After setting the guide pins on the levers assemble the optical micrometer and examine its operation; it is corrected by fitting new springs and also by polishing the lever shafts.

41. Replacement of the horizontal dial

If the horizontal dial has become cracked or damaged in any way as a result of shock or dropping the instrument it must be replaced. To replace the dial dismantle the lower part of the theodolite by the procedure described above. When the defective dial has been removed from the dial bush wash the seating position carefully with aviation gasoline and dry it with a cloth.

The dial, on a special fitting, is fitted in the dial bush. The procedure for fitting the horizontal dial is described above. After the dial has been fitted assemble the lower part of the theodolite and adjust the horizontal dial microscope, i.e. focus it and correct parallax, run and so on.

## 42. Replacement of the vertical dial

Like the horizontal dial, the vertical one is replaced if cracked or damaged. To do this, dismantle the upper part of the theodolite (the telescope and horizontal axis) by the procedure described above. Remove the vertical dial and carefully wash the bearing and then wipe it with a cloth.

The procedure for fitting the vertical dial is described above. After it has been fitted assemble the upper part of the theodolite and adjust the vertical dial microscope.

PART 2

# OPTICAL THEODOLITE TYPE ThB

## Chapter 6

## GENERAL INFORMATION

### 43. Description of theodolite

Optical theodolite ThB, like type OT-02, is a high-precision geodesic instrument. It is comparatively light in weight and convenient in use. The images of the graduations of the horizontal and vertical dials are transmitted by the optical system of the objective of the horizontal and vertical dial microscopes onto a common field of vision of the reading microscope, the eyepiece of which is located alongside the telescope eyepiece. Dial readings are made with a single optical micrometer with a scale calibration of one second per division. Tenth parts of a second are estimated by eye.

The theodolite telescope is straight, of astronomical type, and has internal focussing. The horizontal and vertical dials are made of optical glass. The instrument is provided with electric lighting. The theodolite weighs 10.5 kg, the carrying case and fittings 7 kg, the tripod 9 kg, and the centering plate 4.5 kg.

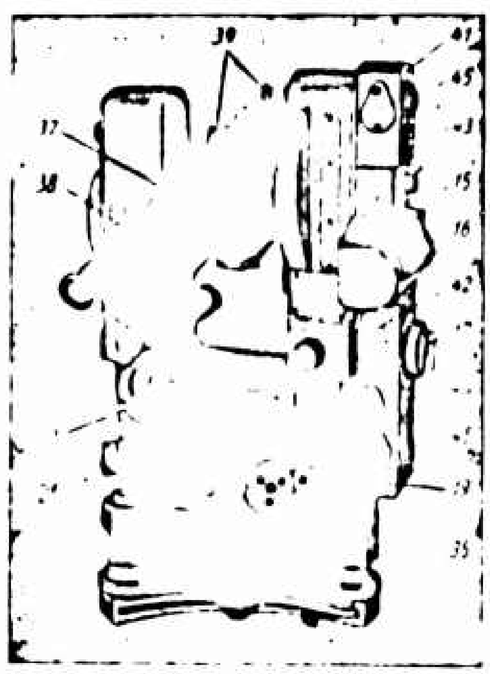
Optical theodolite ThB consists of two main parts: the upper and lower, which are joined together. General views of the theodolite are given in Figs.46, 47, 48 and 49.

The base plate 1 which serves as a basis for the levelling screws is secured to the centering plate or tripod by a fixing screw or a special screw.

GRAPHIC NOT REPRODUCIBLE

Fig. 46. Theodolite ThB from the micrometer side

1 - base plate; 2 - levelling screw; 3 - red spots; 4 - aztmuth guide screw knob S; 5 - circular level; 6 - reading microscope; 7 - telescope locking screw; 8 - optical micrometer drum; 9 - dial image selector knob; 10 - horizontal dial alidade locking screw; 11 - carrier; 12 - carrier support; 46 - cover; 47 - cover; P - screw plug.



GRAPHIC NOT REPRODUCIBLE

Fig. 47. Theodolite ThB (from the level side, on stand)

15 - prism for observing contact level; 16 - swivelling cover; 17 - switch; 19 - catch; 20 - horizontal dial alidade level; 21 - knob for resetting horizontal dial; 35 - rheostat; 37 - telescope focussing ring; 38 - protecting ring for graticule adjusting screws; 39 - front and back sights for approximate aiming of telescope; 41 - top cover; 42 - lower cover; 43 - fixing catch for top cover; 44 - screws with springs for fixing lower cover; 45 - shutter.

The principal component of the lower part of the theodolite is the carrier 11 with two levelling screws 2 and one support 12. The upper part of the theodolite rests on the carrier. The levelling screws are used to set the vertical axis of the theodolite over the plummet.

The socket 28 (Fig.48) in the base is supplied with electricity for lighting the dials and the graticule. The optical plummet 36 (Fig.49) for centering the theodolite is attached to the base of the carrier. This optical plummet has a magnification of 1.25 x , a field of vision of 8°, and can be focussed in the range of 0.2 - 7.2 m. A general view of the optical plummet is given in Fig.50.

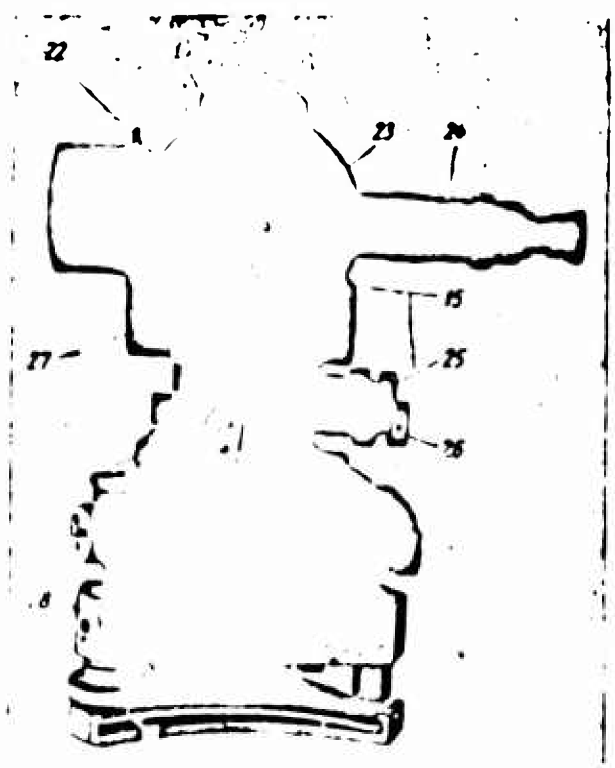



Fig. 48. Theodolite Th8 (from contact level side)

14 - condenser for electric lighting of vertical dial; 15 - prism for observation of contact level; 22 - arm with socket for electric lamp; 23 - retaining screw for arm 22; 24 - telescope; 25 - outer knob of telescope double adjusting screw; 26 - outer knob of contact level double adjusting screw; 27 - window for natural lighting of contact level; 28 - plug socket for electric power supply.

Before centering a sharp image of the graticule is obtained by turning the eyepiece ring of the optical plummet and turning the focussing ring to obtain a sharp image of the centre position. There is an adjusting screw for adjusting the optical axis of the optical plummet graticule relative to the vertical axis of rotation of the instrument.

The carrier levelling screws are of the closed type and so are protected from dirt and dust. The travel of each screw can be adjusted.


Fig. 49. Theodolite Th8 (with covers 41 and 42 removed)

13 - lighting mirror for vertical dial; 18 - lighting mirror for horizontal dial; 29 - contact level cover; 30 - condenser for electric lighting of contact level and horizontal dial; 31 - level adjusting screws for horizontal dial alidade; 32 - microscope eyepiece; 33 - telescope eyepiece; 34 - telescope eyepiece protective device; 35 - rheostat; 36 - optical plummet; 39 - fore and back sights for approximate aiming of telescope; 40 - adjustment for graticule lighting; 50 - plate; 51 - catch for reading microscope.

A dimmer rheostat 35 for the electric lighting of the dial graduations is fitted in the carrier. The base plate 1 (Fig.46) is secured to the carrier by a locking catch.

The horizontal dial is fixed to a dial bush which rotates around the vertical axis main bearing. When the horizontal dial is being adjusted it is turned by turning the knob 21 (Fig.47). The main bearing of the vertical axis is secured to the carrier. The upper part is the most important and complicated part of the theodolite.

The vertical axis of the instrument is cylindrical and rotates in a cylindrical sleeve (or main bearing), and is fixed to the alidade part of the instrument; the horizontal axis of the instrument is a complicated assembly (see Fig.57) to which the telescope and reading microscope are fixed.

One end of the horizontal axis fits into the eccentric bearing 1 and the other end into the bearing of the vertical turntable housing 3.

Fig. 50. Optical plummet of theodolite Th8

The horizontal and vertical dials are illuminated by identical rotating mirrors 13, 18 (Fig.49). The contact level is illuminated through the window 27 (Fig.48) which is closed by a tilting cover 16.

For operation with electric lighting it is necessary to fit the covers 41 and 42 (Figs. 47 and 51) first setting the lighting mirrors 13, 18 in the path of the light from the condensers 14, 30. The cover 31 is secured by the catch 43 (Fig.47) and the cover 42 by the screws with springs 44. If it is required to correct the position of the lighting mirrors the shutters 45 on the casings are tilted and the adjustment is made through holes.

The horizontal dial and contact level are lit by an electric lamp fitted to the knob 17 (Fig.47) of the electric light switch. Light from the lamp passes through the upper lens of the condenser 30, falls on the contact level and through the lower condenser lens 30 (Fig.49) to the lighting mirror 18.

The vertical dial and telescope graticule are lit by an electric lamp attached to the arm 22 (Fig.48). The light from this lamp passes through the condenser lens 14 and falls on the lighting mirror 13.

To change the electric lamp which lights the horizontal dial and contact level, withdraw the pins which are in slots in the knob 17 (Fig.47) and, holding it in the withdrawn position, unscrew and remove the knob 17 to which the lamp holder is fixed.

To replace the lamp which lights the vertical dial and the telescope graticule undo the retaining screw 23 (Fig.48) and remove the arm 22 to which the lamp holder is fixed. The electric lighting of the horizontal and vertical dials, of the contact level and graticule are switched on together by turning the knob 17.

When making astronomical readings the eyepiece lenses are removed from the telescope and reading microscope and replaced by suitable prisms. If the light is too bright, so that it is difficult to make observations, a red or yellow light filter is placed on the telescope eyepiece.

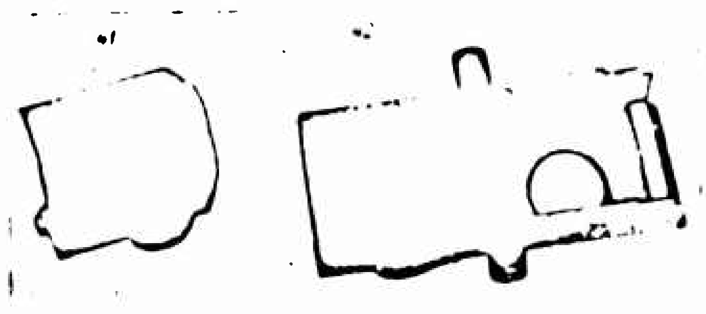


Fig. 51. Cover for lamp
41 - top cover; 42 - lower cover.

Two flat spring supports 34 (Fig.49) protect the telescope eyepiece from shock if it hits the lower part of the stand. The telescope graticule lighting is adjusted by turning the adjustment knob 40. The optical micrometer scale is illuminated together with the dials.

The contact level of the vertical dial alidade has a scale with an inscription every fifth division which is viewed through the prism 15 (Fig.48) from the telescope eyepiece side. The level 3 is calibrated in divisions of 10" for 2 mm. As this prism can be turned over, the level bubble can be observed with the instrument in the centre-right (CR) and centre-left (CL) positions.

Altogether the theodolite has three levels. The second level which is calibrated at 2' per division serves to bring the vertical axis of rotation approximately to the plummet centre position. The cylindrical level on the horizontal dial alidade with a calibration of 10" per 2 mm is used for accurate adjustment.

The telescope is focussed on the graticule by the focussing ring and on the object by the telescope focussing ring 37. Under the protecting ring 38 (Fig.47) there are adjusting screws for the telescope graticule.

In the CL position the optical micrometer is on the right-hand upright of the stand. Fig.46 shows the optical micrometer drum 8, above it is the telescope locking screw 7 and below it the dial image selector knob 9 which is turned to select the image of the horizontal or of the vertical dial. The images of the dial calibrations are observed through the reading microscope 6.

Before taking readings the illumination of the field of vision of the reading microscope is made sufficiently clear and uniformly bright by adjusting the lighting mirrors 13 and 18 (Fig.49).

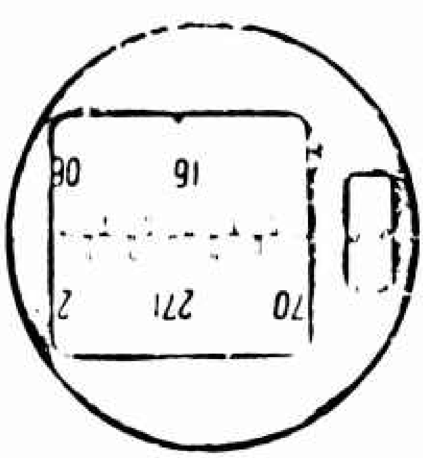



Fig. 52. Field of vision of reading microscope with micrometer in initial position

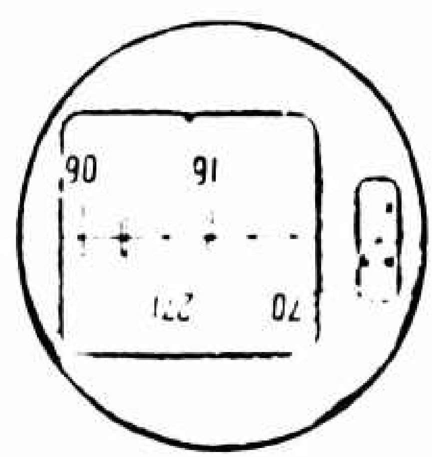



Fig. 53. Field of vision of reading microscope when reading 90°56'36.5"

There are two windows in the field of vision of the reading microscope (Figs.52 and 53): the left-hand one is the larger and the right-hand one is the smaller. The left-hand window displays the image of the diametrically opposite double lines of the dial and the numbers marked against them (the index is in the upper part) and the right-hand window displays the image of the scale of the optical micrometer and the numbers against the graduations. The dial graduations are made to coincide accurately by turning the micrometer drum.

In the left-hand window (Fig.53) the inscription against the upper double line to the left of the index indicates the number of degrees ($90^{\circ}$); the number of intervals between the upper line and the lower one which differs from the number on the upper line exactly by $180^{\circ}$ gives the number of tenths of minutes (50 minutes).

In the right-hand window (Fig.53) on the left of the scale the number of whole minutes is read directly from the index of the micrometer scale (6 minutes) and on the right the number of whole seconds (36 seconds), and the tenths of seconds are estimated by eye (0.5 seconds). Thus the complete reading is $90^{\circ}56'36.5''$.

In order to make a reading on the vertical dial the selector 9 is turned until the letter H appears in the slot in its knob and on the knob itself, then the dial graduation lighting is adjusted.

The subsequent procedure and the actual reading are just the same as in reading the horizontal dial.

The zenith distance is calculated by the formula:

$$Z = \frac{КЛ - КП + 360}{2}. \qquad (24)$$

and the location of the zenith from the formula

$$M_t = \frac{КЛ + КП - 360°}{2}.$$

The following formula is used to check the calculation of the zenith distances:

$$Z = КЛ - M_t$$

and

$$Z = M_t + 360° - КП.$$

## 44. The optical system

The optical system of theodolite ThB is represented diagrammatically in Fig.54 and consists of the following main assemblies and components, the optical systems of:

(a) the telescope;

(b) the horizontal dial microscope objective;

(c) the vertical dial microscope objective;

(d) the micrometer;

(e) the reading microscope;

(f) the optical plummet, and

(g) the horizontal and vertical dials.

The telescope optical system consists of a compound objective, a graticule and two interchangeable eyepieces.

The principal characteristics of the telescope are:

Tube magnification, 34 x and 48 x

Angle of field of vision, $1^{o}14'$; $0^{o}52'30"$

Focal length of objective, 259 m

Equivalent focal length of objective, 381 mm
Diameter of free aperture of objective, 60 mm
Focussing range, from 10 metres to infinity
Focal length of eyepiece, 11.25 mm and 8 mm
Magnification of eyepiece, 22 x and 31 x
Field of vision of eyepiece, 39°, 40°
Diameter of eyepiece iris, 1.75 mm and 1.25 mm

The telescope objective consists of the actual objective 4, 5 (Fig.54) and a focussing lens 3 (built up from two lenses), the graticule consists of two cemented plane-parallel plates 2, one of which carries the hair lines (Fig.55).

The interchangeable eyepieces are orthoptical and consist of a cemented three lens assembly and eyepiece lens.

The graticule position can be adjusted horizontally and vertically, the adjusting screws are covered by a protecting ring 38 (Fig.47).

The optical system of the horizontal dial microscope objective consists of a lighting prism 30 (Fig.54), a horizontal dial with condenser 31, alidade prisms 29, 26 (with a system of transmitting lenses 28, 27) the horizontal dial 25, a swivelling prism 23 and objective 22, 21 with a magnification of 3.05 $^{x}$.

The optical system of the vertical dial microscope objective consists of a vertical dial lighting prism 45, with condenser 46, alidade prisms 44, 41 with transmitting system lens 43, 42, the vertical dial 40, the prism unit 38, 37, the objective 36, 35, with a magnification of 3.82 $^{x}$, the prism 34, the collector 19, and the selector prism 20.

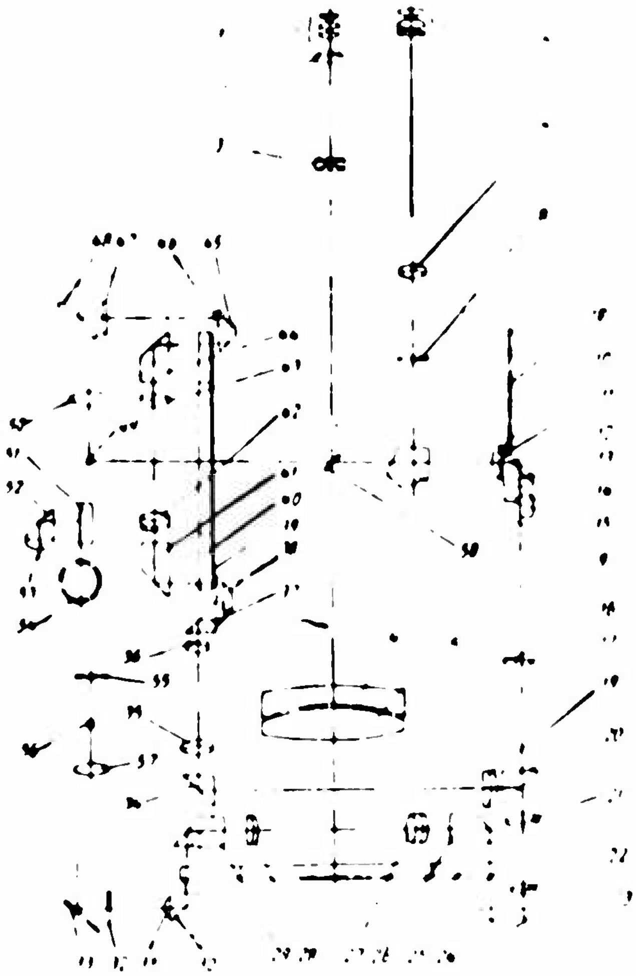


Fig. 54. Diagram of optical system of theodolite ThB

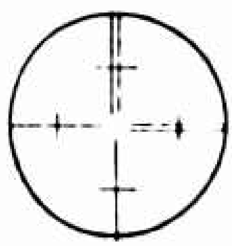


Fig. 55. View of graticule in field of vision of telescope

The horizontal and vertical dials are lit by mirrors and the lighting system consisting of electric lamps 49, 56 and condensers 50, 57. Moreover, light from the electric lamps falls on the metal mirror 58 to light the telescope graticule 2.

The optical system of the micrometer is arranged in such a way that the images of the graduations of the horizontal and vertical dials and also of the graduations of the scales and index of the micrometer appear in the same plane and can be read through the reading microscope.

The optical system of the micrometer consists of stationary wedges 16, 17, micrometer wedges, 14, 15, the separating prism unit 13, 12, the micrometer scale 18, and the plane-parallel plate 11 with diaphragm (Fig.54).

The reading microscope consists of the collector lens 10, the reading microscope prism 9, the objective 7 and the eyepiece 6. It is common to the optical systems of the objectives of the horizontal and vertical dial microscopes, since both objectives are focussed on a single plane which passes through the line of separation of the separating prism unit 13, 12 and is perpendicular to the axis of the collecting lens 10 of the reading microscope.

The magnification of the reading microscope is 16.6 x and the overall magnification of the microscope for the horizontal dial is $50.5^{x}$ and for the vertical dial $63.5^{x}$. The field of vision of the reading microscope in the horizontal and vertical dials is $2^{o}$ (in dial divisions).

The optical system of the plummet (Fig.56) consists of a prism 2, an objective 3 and an eyepiece 4. The hair line is marked on the first lens of the eyepiece.

The horizontal and vertical dials

The horizontal and vertical dials of theodolite ThB are made of optical glass. The diameters of the circles on which the graduations are marked is 125 ± 0.05 mm, for the horizontal dial, and 100 ± 0.05 mm for the vertical dial. The total error in the diameter of the horizontal dial does not exceed ± 2" and the smallest division of the dials is 20 minutes*; the thickness of the dial graduation lines is 0.01 ∓ 0.002 mm.

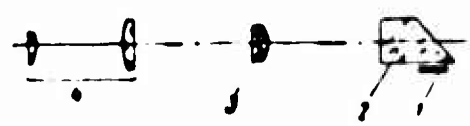


Fig. 56. Diagram of the optical arrangements of the optical plummet
1 - cover glass; 2 - prism; 3 - objective; 4 - eyepiece.

The tolerated eccentricity of the graduated circle relative to the central aperture of the dial is of the order of 0.1 mm and the plane surfaces of the dial should not be more than 20" out of parallel.

Optical micrometer scale

The optical micrometer scale is arranged in such a way that displacement of the dial graduations by 10' caused by moving the micrometer wedges corresponds to a scale displacement of 600 divisions in the field of view of the reading microscope (scale length 55 mm).

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* If the dial is subdivided into $400^g$ (grades), the smallest division is $20^c$.

If the dial is divided into 360° the scale is divided into 600 divisions each of 1" and if the dial is divided into 400 grades the scale is divided into 1000 divisions each of $1^{cc}$.

Microscopes and path of light

In the optical system of theodolite ThB the horizontal and vertical dial microscopes are systems in which the optical micrometer and the reading microscope are common to both. Let us consider the path of light in the microscope of the horizontal dial (Fig.54).

Light from the electric lamp 56 passes through the condenser 57 to the mirror 33. The light reflected from the mirror passes through the prism 30 with the condenser, and lights the dial graduations. Then the light passes through the alidade prism 29 through the system of lenses 28, 27 and the alidade prism 26 which reflects the light onto the diametrically opposite part of the horizontal dial 25. Close to the graduations of this part of the dial there is also an image of the graduations located on the diametrically opposite part of the dial. The system of transmitting lenses 28, 27 has a magnification of unity and gives an image of the first graduations in the path of the light beam in the plane of the graduations of the opposite part of the dial; as the light beam from them passes through the optical parts 29, 28, 27, 26 the brightness of the image of these graduations is weaker than that of the opposite ones. The further path of the light is downwards to the prism 23 which is fixed under the horizontal dial. This prism directs the image of the diametrically opposite graduations of the dial to the microscope objective of the horizontal dial 22, 21.

The light passes through the objective (the selector prism being out of line) and the light beams from the corresponding graduations pass through their optical wedges 16, 17 (refractive angle 1°07'30"), the light beam then passes through the wedges 14, 15 of the optical micrometer with refractive angles of 1°07'30".

The angles of the optical micrometer wedges and of the wedges above them are opposite in direction. The wedges of the optical micrometer differ in thickness, they are made in this way in order to compensate the difference in the length of the path of light from the opposite graduations of the dial.

After passing through the optical micrometer wedge the light reaches the separating prism unit 13, 12 consisting of a prism to which is cemented a wedge with a refracting angle of 30 minutes. Part of the prism surface under the wedge is silvered. The beam of light which passes through the thick wedge of the optical micrometer 14 passes through the separating prism to the wedge and is reflected from its back surface and re-enters the prism; as the beam leaves the wedge an image of the dial graduations is obtained. The second beam which enters the separating prism from the thin wedge, and receives an image of the diametrically opposite graduations of the dial. The line of separation between the images of the diametrically opposite graduations is the edge of the silvered surface of the prism. To the side of the separating prism is cemented the micrometer scale lighting prism on which the index of the micrometer scale is marked, and to the front the collector lens 10 with a plane-parallel plate on which the diaphragms with indexes are marked.

The images of the dial graduations, the micrometer scale divisions and also the micrometer scale index are in a single plane and are examined through the reading microscope which consists of the collector lens 10, the prism 9, the objective 7 and the eyepiece 6.

The path of light in the vertical dial microscope is as follows (Fig.54). Light from the electric lamp 40 passes through the condenser 50 to the mirror 48 (in Fig.54 the mirror 48 is not orientated). The light reflected from the mirror passes through the prism 45 with the condenser 46 and illuminates the graduations on the vertical dial. Further, the light passes through the alidade prism 44 through the lens system 43, 42 and the other alidade prism 41 which reflects the light from the diametrically opposite part of the vertical dial. Near the graduations of this part of the vertical dial there is produced an image of the graduations on the opposite part of the dial. The transmitting system of lenses 43, 42 has a magnification of unity and gives an image of the first graduations in the path of the beam of light in the plane of the graduations of the opposite part of the vertical dial. As the light beam from the first graduations passes through the optical parts 44, 43, 42, 41, their images are somewhat less bright, than the opposite ones. The light then passes through the unit with prisms 38, 37, which is behind the vertical dial and in which the light undergoes multiple reflection and is directed to the objective of the vertical dial microscope 36, 35. Passing through the objective the light goes through the prism 34 and the lens 19 and reaches the selector prism 20, and further to the optical wedges 16, 17, and into the optical micrometer. The path of light in the optical micrometer is described above.

## 45. System of axes

The horizontal axis system of the instrument (Figs.57,58) includes the following components: the adjustable bearing 1, the horizontal axis 2, the turntable bearing 3, the bearing bush 4 and the alidade part of the vertical dial 5. One end of the horizontal axis (in the CL position) runs in the adjustable bearing 1 which is in the right-hand upright of the stand (see Fig.70). The outer diameter of the cylindrical part of the bearing is eccentric relative to the inner diameter which serves as the bearing of the horizontal axis. Therefore, by releasing three screws which secure the bearing to the support upright, and turning the bearing, the slope of the horizontal axis can be adjusted relative to the vertical axis of the theodolite. Between the adjustable bearing 1 (Fig.70) and the horizontal axis there is a gland. At the other end the horizontal axis is supported by the turntable bearing 3 which is secured to the bearing bush 4 and the vertical turntable housing. The axis of the alidade part of the vertical dial runs in the bearing bush 4 (Fig.58) , there is another gland between the horizontal axis and the cover of the vertical turntable housing.

The system of vertical axes of the instrument (Fig.59) includes the following components: the vertical axis 1, the vertical axis main bearing 2, and the dial sleeve 5.

The vertical axis is screwed securely to the stand,(Fig.60) and turns in its main bearing 2 (Fig.61) which is secured to the

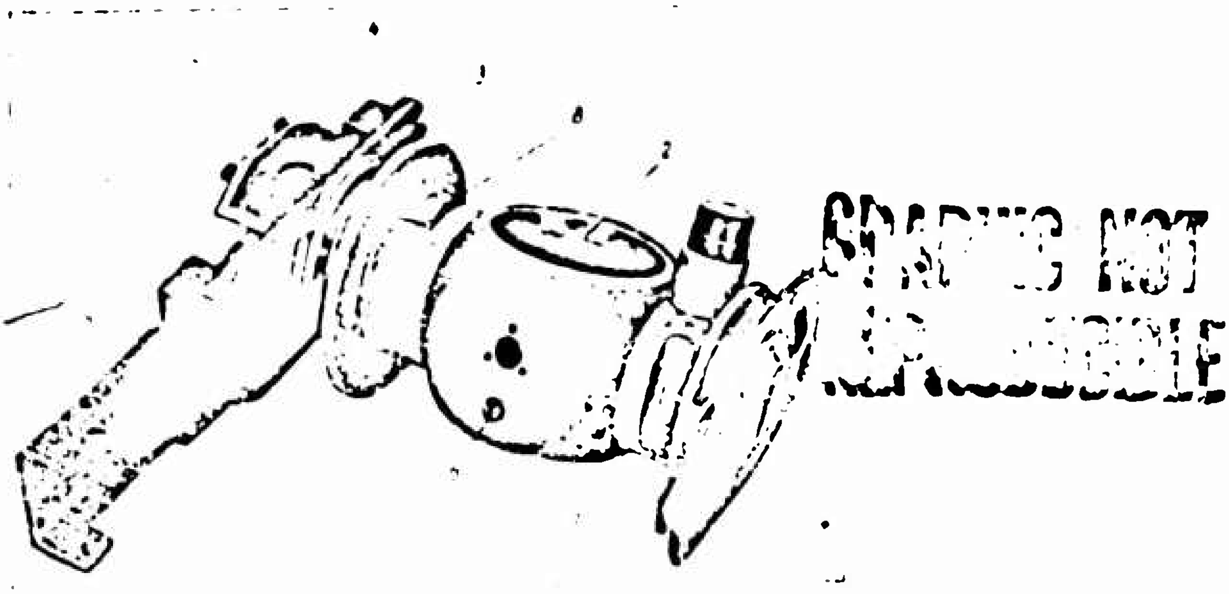

Fig. 57. Horizontal axis with bearings and alidade part

1 - adjustable bearing; 2 - horizontal axis; 3 - turntable bearing; 4 - bearing bush; 5 - alidade part; 6 - telescope fixing screw; 7 - window; 8 - window of bearing bush limiter.

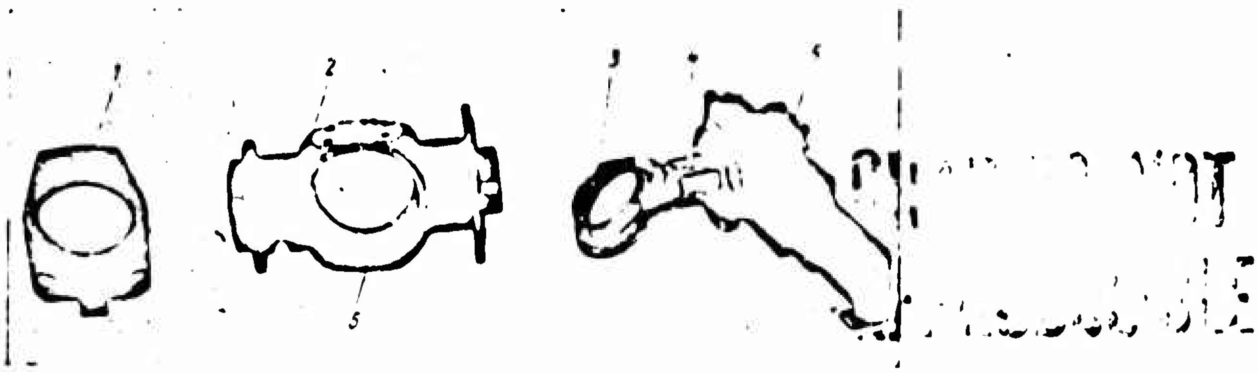


Fig. 58. Horizontal axis system

1 - adjustable bearing; 2 - horizontal axis; 3 - turntable bearing; 4 - bearing bush; 5 - alidade part; 6 - telescope fixing screw.

dial casing sleeve by three screws. The dial casing sleeve 6 (Fig.59) is attached to the carrier by three screws.

The vertical axis thrust-bearing 7 is located at the bottom of the dial casing; it serves as a bearing for the spherical end of the vertical axis. Fig.62 shows the dial sleeve with horizontal dial and driving gear. The dial sleeve is fixed to the vertical axis main bearing by a spring ring which runs in the half-ring 3 (Fig.61) and the dial sleeve and dial can turn around the vertical axis main bearing. The dial is reset by turning the knob 21 (Fig.47), on the axis of which is a drive which connects the dial sleeve to the gears.

The vertical pressure of the entire upper part of the theodolite is only transmitted through the vertical axis thrust bearing (Fig.59) and there is hardly any pressure on the side surface of the vertical axis 1.

## 46. Optical micrometer

The optical micrometer is used to make readings of the horizontal and vertical dials. The horizontal and vertical dials are sub-divided at intervals of 20', the micrometer scale has 600 divisions each of 1", and displacement of the scale over its entire length corresponds to 10'. General views and individual components of the optical micrometer are shown in Figs.63, 64 and 65. The optical micrometer is constructed as follows. All the parts of the micrometer are secured to the base plate 1 (Fig.63), the slider 3 runs in the guide 2, the rack 5 (Fig.65), the micrometer scale 4 and the micrometer wedge mounting 6 are all secured to the slider 3.

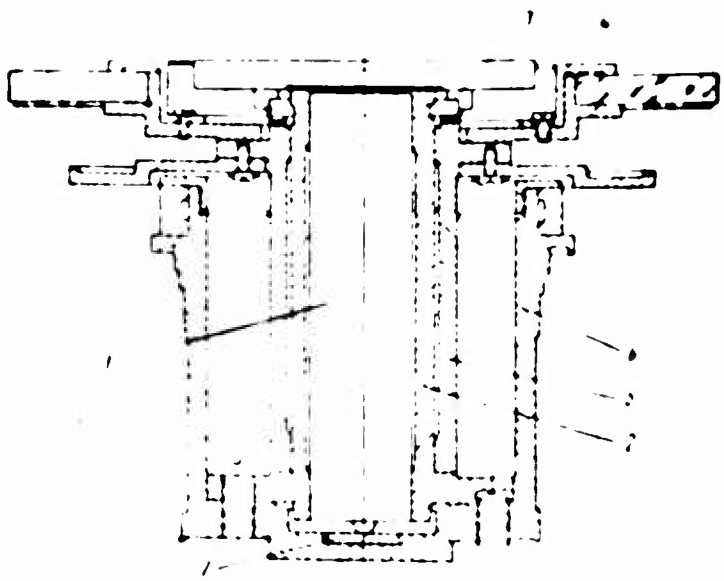

Fig. 59. Vertical axis system

1 - vertical axis; 2 - vertical axis main bearing; 3 - split ring; 4 - special dial retaining ring; 5 - dial bush; 6 - dial casing bush; 7 - vertical axis thrust bearing.

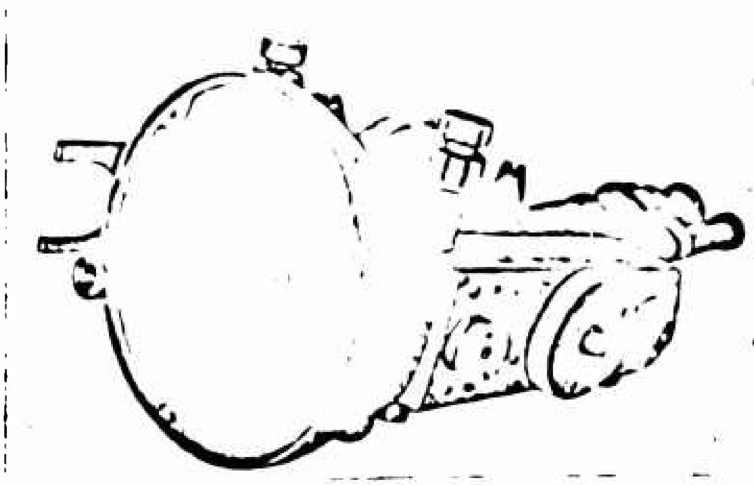

Fig. 60. Upper part of theodolite with vertical axis

The rack 5 engages with the pinion 7 (Fig.64) on the drum of the optical micrometer. As the drum turns the slider 3 moves on the guide 2 together with the scale and the micrometer wedges. Above the optical micrometer wedges there is a mounting 10 (Fig.63) with the separating prism unit, and under its wedges the mounting 8 containing the stationary wedges and the mounting 9 containing the dial image selector prism. As the micrometer wedges and scales are securely joined together defects in the mechanism such as slackness or play can have no effect.

Fig. 61. Lower part of theodolite
2 - vertical axis main bearing; 3 - half ring; 4 - special dial securing ring with six retaining screws.

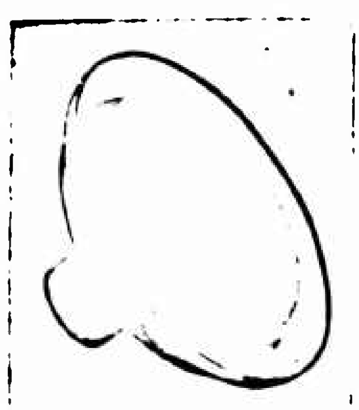

Fig. 62. Horizontal dial on bush

The micrometer operates as follows. To make a reading on the dials the images of the diametrically opposite graduations of the dial are made to coincide. This is done by turning the micrometer drum which is located on a common shaft with the pinion 7(Fig.64) so moving the rack 5 with the slider 3 (Figs.63, 65).

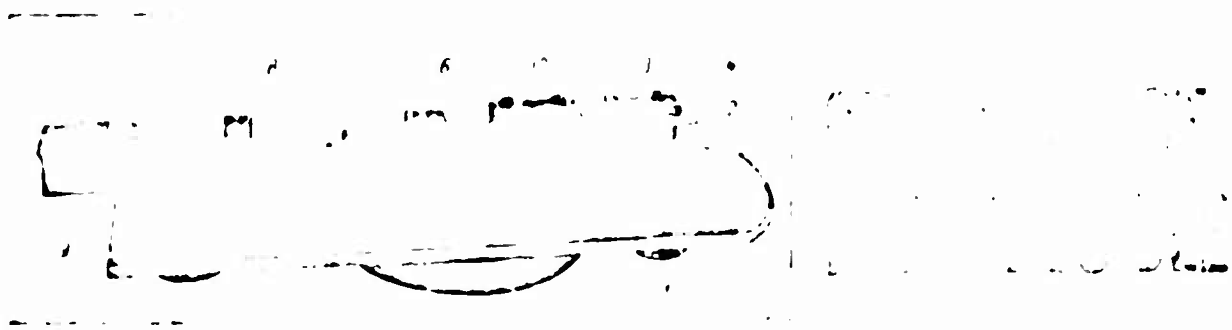

Fig. 63. Optical micrometer

1 - micrometer base; 2 - guide; 3 - slider; 4 - micrometer scale; 6 - mounting with micrometer wedges; 8 - mounting with wedges; 9 - mounting for dial selector prism; 10 - mounting for separating-prism unit.

Movement of the slider alters the position of the micrometer wedges so that the sighting rays are displaced until the images of diametrically opposite graduations coincide.

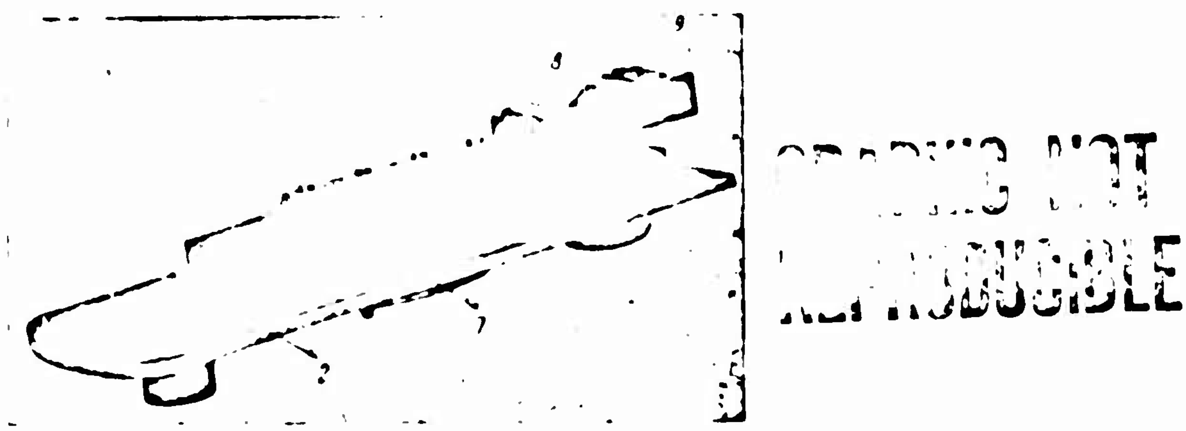

Fig. 64. Micrometer base

2 - guides; 7 - pinion; 8 - mounting with wedges; 9 - mounting with selector prism.

After the opposite graduations have been made to coincide dial readings are taken on the micrometer scale aginst the diaphragm index.


Fig. 65. Components of optical micrometer

4 - micrometer scale; 5 - rack; 6 - micrometer wedges; 11 - separating prism unit.

# Chapter 7

## CHECKING AND FITTING THE INDIVIDUAL COMPONENTS OF THE THEODOLITE ThB

The method of checking optical theodolite ThB before starting work is similar to that used in checking optical theodolite OT-02. Therefore, we describe only the examination and adjustment of the individual components of the theodolite ThB which is necessary when making repairs.

When an optical theodolite is repaired certain adjustments are necessary, particularly if individual components or assemblies have been replaced. On the ThB theodolite these adjustments include: fitting the horizontal dial, fitting the vertical dial, assembly and adjustment of the telescope objective, adjustment of the optical micrometer, fitting of the reading microscope prism, adjustment of the optical system of the horizontal dial microscope, checking the angle between the horizontal axis of the telescope and the vertical axis of the instrument, adjusting the optical system of the vertical dial microscope, fitting the dioptric ring and fitting the graticule just as in theodolite OT-02, correcting $M_z$ of the vertical dial, checking the collimation error, checking the optical plummet.

Special lubricants are applied whilst the components are being adjusted and during final assembly. After final assembly the instrument is hermetically sealed by applying a special compound with a soldering iron.

## 47. Fitting the horizontal dial

The process of fitting the horizontal dial of theodolite ThB is similar to that of theodolite OT-02, i.e., fitting of the dial consists in centering it on the dial sleeve relative to the vertical axis of the instrument. The dial eccentricity should not then exceed 10", and the alidade eccentricity 20".

The dial with the lower part of the theodolite is set up on a special stand (see Fig.9). Slacken the six screws in the special retaining ring 4 (see Fig.59) which clamps the dial to the dial sleeve, centre the lower part of the theodolite relative to the centre of the device. First focus the microscope on the images of diametrically opposite graduations of the dial, then orientate the microscope on the graduations and proceed to centre the dial. Displace the dial relative to the dial sleeve by the special screws provided on the adjusting device. Continue centering until the above mentioned requirements are met after which the six screws on the special ring 4 are tightened to secure the dial on its sleeve.

## 48. Fitting the vertical dial

The vertical dial is set up on a special device (Fig.66) in such a way that a line passing through diametrically opposite graduations (90 - 270$^{\circ}$) is perpendicular to the axis of the aperture for the telescope in the horizontal axis.

A reading is taken with a microscope in the first position, it is then transferred to position 2 and another reading is taken. If there is much difference between the readings the dial position must be altered. Checking is continued until the difference between the readings does not exceed 3 - 4 minutes. This check makes it easier to reduce the value of $M_z$ of the vertical dial.

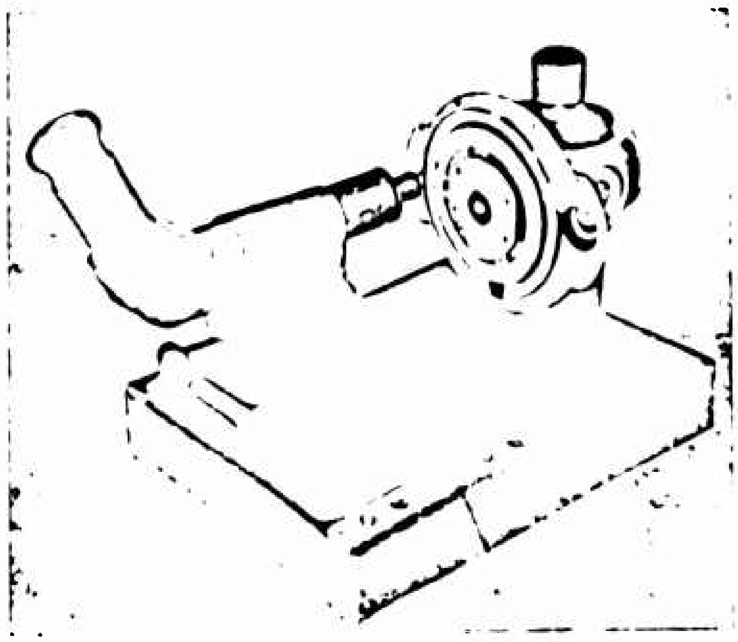

Fig. 66. Device for fitting the vertical dial
2 - support for use when microscope is in the second position.

Fix to the devices shown in Figs. 9 and 10 the shaft which carries the horizontal axis with the vertical dial. Focus the microscopes on the images of the graduations and release the clamping ring of the vertical dial, then centre the vertical dial. The eccentricity of the vertical dial should not exceed 20". After the vertical dial has been centred it is locked by the special ring with screws.

## 49. Assembly and adjustment of the telescope objective

The optical system of the telescope of theodolite ThB consists of a tele-objective, graticule and an orthoscopic eyepiece. The objective consists of a two-lens actual objective and a two-lens focussing component (or focussing lens).

If it is required to replace the objective lenses and the data required for optical calculation are not available, it is necessary to measure the following properties: the focal length, the thickness of the lenses on the centre line, the radii of curvature and refractive indices. The radii of curvature of the lenses are measured with a precision spherometer. Measurement of the focal length and refractive indices of the lenses is described in Appendices 1 and 2. The manufacture of new lenses is based on the results of the measurements.

In assembling and adjusting the theodolite telescope objective, the air gap between the first and second lenses of the objective must be kept constant by adjusting the spacer ring and then centering. If the spacer ring is undamaged, then only centering is necessary after the objective has been assembled. To do this the tube is first set up in an optical bench. Observe in the tube a point located at the focus of the collimator of the optical bench and determine the quality of centering. Good centering can be achieved, provided that the components are of good quality, by turning the lenses of the objective relative to one another. After centering the telescope optical system a mirror is set in the collimator focus and it is observed in the telescope through the collimator and the quality of the image and the resolving power of the telescope objective are determined. The resolving power in the centre of the field of vision should be of about 2".5.

## 50. Adjustment of the optical micrometer

A general view of the optical micrometer and its components is shown in Figs. 63, 64, 65. First set the micrometer wedges 6 (Fig.65) by means of the autocollimator and then make a preliminary setting of the micrometer scale and the fixed wedges 8 in their mountings (using the autocollimator).

The most important assembly of the optical micrometer in the theodolite ThB is the separating prism unit (Fig.67) which consists of the following parts. (a) prism, (b) a wedge of 30', (c) a plane-parallel plate, (d) a collecting lens for the reading microscope, (e) a prism for illuminating the micrometer scale, (f) a plate which secures the wedge to the prism.

The plane of the wedge to which the prism is cemented is partially silvered, thus forming a separating line between the images of diametrically opposite graduations of the dial. The opposite plane of the wedge is completely silvered. The plane-parallel plate (c) carries the diaphragms. All the components of the separating prism unit are cemented together. Cementing the separating prism unit is a complicated process because the following conditions must be met.

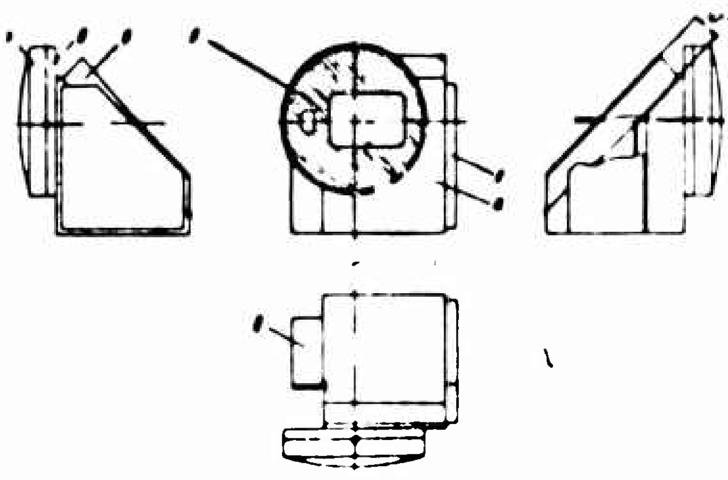

Fig. 67. Diagram of separating prism unit

The line of separation (the silvered edge) and the index must be in the centre of the aperture of the diaphragm with a tolerance of 0.05 mm. The line of separation must be parallel to the edge of the diaphragm with a tolerance of 10'. The cemented planes of the wedge and prism must be of high quality, and therefore the cementing must be done accurately to avoid scratching or other damage. The outlet faces of the prism (a) and (e) must be parallel with a tolerance of 10'. When the components are cemented there should be an angle of 30' with a tolerance of $\pm$ 1' between the flats of the prism (a) and the reflecting flat of the wedge (b).

To protect the wedge against creep, the edge of the junction between the wedge and the prism and also the plate f which secures the wedge to the prism are secured with a mixture of fish-glue and gypsum.

When the quality of the cementing has been checked the separating prism unit in its mounting is fitted in the micrometer.

The optical micrometer is finally adjusted in the instrument and the range of displacement of the micrometer scale, its zero position, etc., are set, after which the scale, wedge, and, also, the separating prism unit are finally locked. When the optical micrometer has been adjusted, on looking through the reading microscope the line of separation of opposite graduations of the dial should be in the centre of the diaphragm and parallel to its edge, the micrometer scale index should be in the centre of the diaphragm and the micrometer scale should not be skewed.

51. Fitting the reading microscope prism

In adjusting the microscope optical systems in theodolite ThB it is very important that the prism of the reading microscope should be correctly fitted, i.e. the images of diametrically opposite graduations of the dial should be uniformly lit and arranged in a circle which is an image of the free aperture of the objective of the reading microscope.

Before fitting the prism of the reading microscope check the bearing planes of the prism mountings. The mounting with the prism is then placed in the horizontal axis of the instrument. The prism of the reading microscope is adjusted with the adjusting screws of the mounting through the window 7 (Fig.57). The process of fitting the prism is similar to that used in theodolite OT-02; the inlet face of the prism should be perpendicular to the axis of rotation of the tube and the outlet face symmetrical with the aperture of the reading microscope.

## 52. Adjustment of the optical system of the horizontal dial microscope

Provided that the optical system of the reading microscope and the optical micrometer have been checked, the adjustment of the optical system of the horizontal dial microscope consists in adjusting the optical system of the microscope objective.

The objective of the horizontal dial microscope 22, 21 (Fig.54) is first focussed, so that the dial graduations visible in the field of vision are sharp, by moving the objective and its mounting along the axis. For this purpose unscrew the screws of the cover 46 (see Fig.46), remove it from the stand and release the screws which hold the mounting of the horizontal dial microscope objective. Access is then available to the screws which secure the mounting to the components of the horizontal dial microscope objective.

The prism 23 (Fig.54) which transmits the images of the dial graduations to the microscope objective is adjusted through the window of the closed cover 47 (Fig.46). When a sharp image of the dial graduations has been obtained adjust the alidade part of the optical system of the objective; to do this, unscrew the four screws of the plate 48 (Fig. 68), remove it from the stand and then remove the level of the horizontal dial alidade. Working through the window, unscrew the screws which secure the mounting of the prisms 26, 29 (Fig.54). Look through the reading microscope and move the lenses of the transmitting system 28, 27 until the intervals are equal and there is no parallax between diametrically opposite graduations of the dial. The mounting with the lenses 28, 27 is

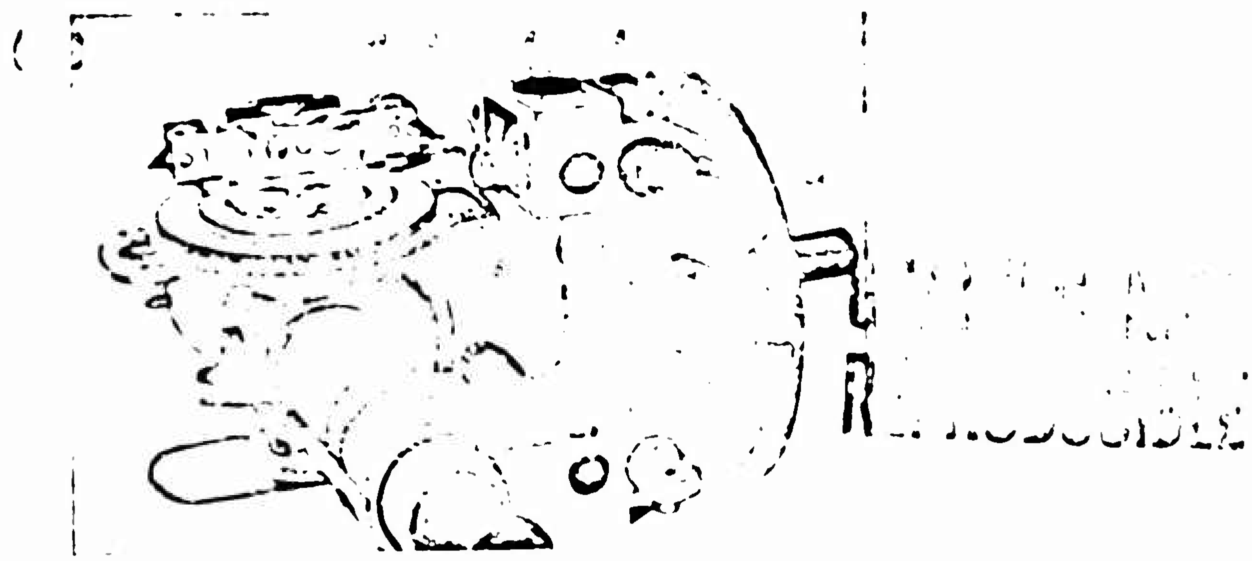

Fig. 68. Upper part of theodolite ThB (housing of vertical turntable, adjusting screws and levels removed)

48 - plate; 49 - alidade base; O - vertical dial microscope objective; B - site for prism unit which transmits images of vertical dial graduations to the microscope objective; A and C - apertures for adjusting objective and prism.

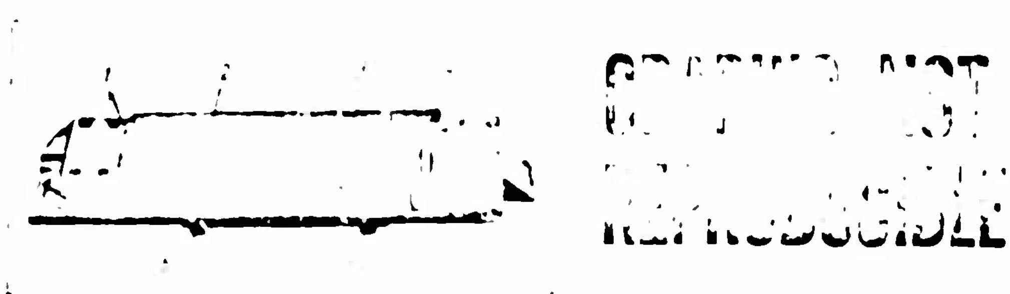

Fig. 69. Alidade part of horizontal dial

1 and 4 - mountings with lenses of transmitting system; 2 and 3 - screws; 5 and 6 - screws which secure the alidade part in the vertical axis.

moved through the two apertures which are closed by the plugs P (Fig.46). Unturn the plug P (from the side of the circular level) unscrew the screws 2, 3 (Fig.69) which secure the lens mountings 28, 27 (Fig.54).

The images of diametrically opposite graduations of the dial which are given by the horizontal dial microscope objective should be in the centre of the field of the diaphragm which is visible in the reading microscope and the graduations should be of equal size and perpendicular to the line of separation. This is achieved by adjusting the prisms 29, 26 and also by displacing the prism 23. The run of the horizontal dial microscope is corrected by altering the distance between components of the microscope objective 22, 21. In preventing run the focus of the objective is somewhat disturbed, consequently, during the process of adjustment it is necessary to make the image of the graduations sharp by moving the objective mounting along its optical axis. The amount of run of the horizontal dial microscope should not exceed 1 division of micrometer scale.

To correct run it is necessary: (1) If the number of divisions on the micrometer scale is greater than 600 the microscope magnification is too high. Therefore increase the distance between the components of the objective (22,21) (Fig.54) whilst displacing the image of the dial graduations by one division (by turning the micrometer drum). (2) Reduce the distance between the components of the microscope objective if the number of divisions is less than 600 because then the magnification of the microscope is too little.

To determine what effect a change in the distance between the components of a microscope objective of theodolite ThB has on the magnification expressed in scale divisions of the optical micrometer, let us denote the size of the half interval between the double graduations of the dial by $l$.

The micrometer scale has 600 divisions each of $\mu = 1$ sec. The calibration of the micrometer scale expressed as divisions of the dial is

$$t = \frac{\mu \cdot l}{n}. \tag{25}$$

where $n$ is the half interval in angular measure.

In the focal plane of the reading microscope the calibration of the micrometer scale expressed in dial divisions is

$$T = t\beta,$$

where $\beta$ is the magnification of the horizontal dial microscope objective.

The half interval in this plane is

$$l_1 = l \cdot \beta. \tag{26}$$

Differentiating, we obtain:

$$dl_1 = l d\beta. \tag{27}$$

Substituting the value of $d\beta$ from formula (20), Section 31, we have:

$$dl_1 = l \cdot K \cdot d\Delta,$$

but

$$d\Delta \approx dD_0,$$

then

$$dl_1 = l \cdot K \cdot dD_0. \tag{28}$$

Converting to finite differences, and bearing in mind that in this case dl can be replaced by T , we obtain:

$$\frac{\mu \cdot l}{n}\beta = lK dD_c,$$

$$dD_c = \frac{\mu\beta}{n \cdot K}, \qquad (29)$$

where

$$K = \frac{x_1 S_2}{f_1 f_2}.$$

Formula (29) can be used to determine the minimum change in distance between objective components of the horizontal and vertical dial microscopes of theodolite 1hB which corresponds to a change in run of about 1 scale division of the optical micrometer.

In correcting run attention must be paid to preventing parallax between the line of separation and the images of the dial graduations at the place where diametrically opposite graduations coincide, which should be opposite to the diaphragm index. To do this, move the prism 23 through the window under the cover 47 (Fig.46). After adjusting the optical system of the horizontal dial microscope objective, the mounting of the lens of the transmitting system 28, 27 and the mounting of the objective 22, 21 are finally secured (Fig.54).

### 53. Checking the angle between the horizontal axis of rotation of the telescope and the vertical axis of the instrument

The angle between the horizontal axis of rotation of the telescope and the vertical axis of the instrument is checked in the following way: the theodolite is set up on a block or on a tripod.

A plumb line is set up at a distance of 10 - 15 m from the instrument. The vertical axis of the theodolite is brought to the plumb position by means of the levelling screws and the cylindrical level on the stand. Then the tube is aimed at the top of the plumb line so that the graticule intersection coincides with the plumb line. The tube is then traversed down the plumb line and it is observed whether the line and the hair lines cross. If this happens, then release the screws which secure the base of the optical micrometer to the stand and remove the micrometer. Release the three screws which secure the right-hand bearing to the stand (Fig.70) and move it. Since the outer diameter of the bearing is eccentric relative to the inner, the right-hand end of the horizontal axis is raised or lowered as the bearing is turned, thus making the necessary correction. The checking is continued until the angle between the horizontal axis of the tube and the vertical is correct.

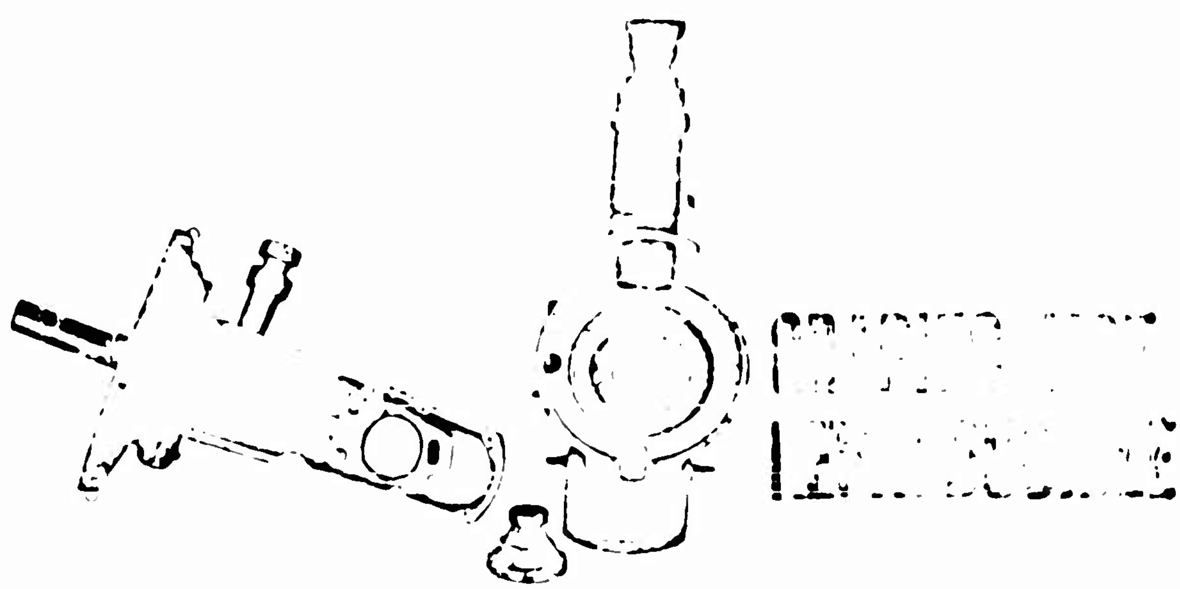

Fig. 70. Telescope, stand and components of the axial system of the horizontal axis
1 - adjustable bearing; 2 - horizontal axis; 3 - bearing; 4 - bearing bush.

## 54. Adjustment of the optical system of the vertical dial microscope

Adjustment of the optical system of the vertical dial microscope consists in adjusting the optical system of the microscope objective, which must be focussed before adjusting the alidade prisms.

In order to move the objective along the axis, remove the base of the cover 42 and the electric lighting switch 17 (see Figs. 47, 48). Then, working through the hole A (Fig.68) the objective can be moved. Obtain a sharp image of the graduations and then proceed to adjust the alidade part of the optical system of the objective of the vertical dial microscope. Look through the reading microscope and move the transmitting system lenses 43, 42 (Fig.54) to prevent parallax between opposite graduations of the vertical dial and make a setting so that the intervals between the graduations on the opposite parts of the dial are equal.

The transmitting system lenses 43, 42 (Fig.54) are moved in the following way. Unscrew the four screws of the plate 50 (Fig.49) and then unscrew the screws which secure the optical components of the alidade part of the vertical dial. The images of diametrically opposite graduations of the vertical dial should be in the centre of the field of the diaphragm visible in the reading microscope, the graduations should be of equal size and perpendicular to the line of separation. This is achieved by adjusting the prism 34 and the change-over prism 20 (see Fig.54).

The prism 34 is adjusted through the hole C (Fig.68), the selector prism 20 is fitted on the micrometer base and, therefore in adjusting the optical system of the objective of the vertical dial microscope the selector prism position is moved in its mounting as necessary, with the micrometer removed from the instrument. The run of the vertical dial microscope is corrected by altering the distance between the components of the objective 36, 35 (Fig.54) through the hole A (Fig.68). To correct run follow the guidance given above, check for parallax between the line of separation and the images of the graduations on the vertical dial, and also check the place at which the opposite graduations coincide.

Diametrically opposite graduations should coincide opposite the index of the diaphragm, this is achieved by moving the prism 34.

The amount of run of the objective of the vertical dial microscope should not exceed 1 scale division of the micrometer. After adjusting the optical system of the objective of the vertical dial microscope the optical parts are finally secured in their mountings.

## 55. Alteration of $M_z$ of the vertical dial

Since the vertical dial is set not only relative to the horizontal axis of rotation but also in such a way that a line passing through diametrically opposite graduations of the vertical dial (0-180°) is parallel to the visual axis of the telescope, $M_z$ is altered in checking the level of the vertical dial alidade.

The theodolite is first set on a level with the stand. The telescope is then adjusted to the horizontal position by the level of the vertical dial alidade and a reading is made on the microscope. When the ends of the bubble of the contact level coincide the microscope reading should be 90°.

Aim the telescope at a staff at a distance of 10 - 15 m from the theodolite and take readings. Then transmit the telescope through the zenith and aim at the same reading on the staff. The reading on the vertical dial when the two ends of the contact bubble coincide should then be 90°. If the ends of the bubble of the contact level have not coincided this is corrected by the adjusting screws.

When the ends of the bubble coincide on the level of the vertical dial alidade (contact level) the readings on the staff and the microscope should remain unaltered. If adjustment of the level correcting screws does not give satisfactory results during the check the prism unit 37, 38 (Fig.54) may be turned.

## 56. Checking the collimation error

The collimation error is determined in the usual way and is corrected by moving the graticule mounting. The check is repeated until the level collimation error 2c does not exceed 10".

## 57. Checking the optical plummet

The theodolite ThB is mounted on a tripod, the levelling screws are adjusted until the vertical axis is in the plummet position and the theodolite telescope is set in the vertical position so that when the upper part of the instrument is turned, there is no appreciable change in the focussing ring of the eyepiece.

A small smooth board covered with paper is placed under the tripod. A theodolite of any suitable construction, such as type TT-5, is set up 10 mm away from the theodolite type ThB.

Sighting on the left and right generating lines of the eyepiece focussing ring of the theodolite ThB telescope, take readings on the horizontal dial and set the alidade to the mean position between them. Then aim the telescope at the board. The check is made by two men, one of them observes through the theodolite telescope and the other, guided by the first, marks on the board two points which coincide with the vertical hair-line of the graticule in the upper and lower parts of the field of vision of the telescope. The two points are joined to give a straight line on the board. Then the theodolite TT-5 is set up at a distance of 10 m and at an angle of 90° to the theodolite ThB. It is again sighted on the telescope eyepiece of theodolite ThB and two points are marked on the board as described above and joined together to obtain the point of intersection between the two lines. Then, whilst looking into the optical plummet, use the two correcting screws, make the cross-hairs of the optical plummet graticule coincide with the place where the lines cross on the board. This check is made more quickly if there are two additional theodolites which are set up at an angle of 90° to the theodolite type ThB.

## Chapter 8

## LUBRICATION, MINOR CORRECTIONS AND PROCEDURE FOR REPLACING INDIVIDUAL COMPONENTS

### 58. Lubrication of axial systems and other assemblies

The axial systems of optical theodolite ThB are lubricated with a special oil (see Section 38). Before lubricating the axis, the bearings and other parts of the horizontal and vertical axis systems are carefully wiped with aviation gasoline and then dried. The axial systems and, particularly, the vertical axis, must be lubricated carefully so that no lubricant falls on the optical parts.

To protect the components against pieces falling off the coating, and aginst the absorption of moisture, the same compound is used as was recommended for coating the parts of theodolite OT-02. This coating is applied to the following components of the theodolite ThB: the dial sleeve (gear), the half rings and spring, the internal surface of the horizontal dial casing, the mounting of the level bulb, the inner surface of the stand, the base of the micrometer, the inner surface of the vertical turntable housing, the telescope casing, the telescope seating places, the frame of the focussing lens mounting (on the outside), the cover of the vertical turntable housing.

Components near to the optical parts are covered with the same compound as in theodolite OT-02. This is applied to the following components and assemblies of theodolite ThB: the mounting of the dial alidade prisms and of the vertical turntable, parts of the optical micrometer, the dial sleeve (the seating place and clamping ring), the mountings of the objectives, lenses, and horizontal and vertical dial microscope prisms, the telescope body, the graticule mounting body, the body of the reading microscope, the eyepiece mountings of the telescope and the reading microscope, the reading microscope prism mountings. The seating places of the vertical and horizontal dials, and also the alidade prisms are wiped with a cloth which has been moistened with this lubricant.

To ensure that the instrument is hermetically sealed all the joining parts which prevent access to the interior of the theodolite are also coated with compound after final adjustment. The following are the joints on the theodolite to which this applies: between the frame of the horizontal dial and the stand, between the vertical turntable housing and the stand, between the base of the micrometer and the stand, between the cover of the vertical turntable housing and the stand, between the horizontal axis and the stand, and the joints between the telescope body and the horizontal axis and with the objective mounting. The same compound is used as for theodolite OT-02.

All the covers and the frame which are to be coated with compound must be wiped with a clean cloth and where necessary painted.

## 59. Correction of defects in the axial system

Cause of defects

The following difficulties may occur in the axial systems when working with the theodolite type ThB: difficulty in rotating about the vertical axis, difficulty in rotating the telescope or jamming of the vertical axis system.

Difficulty in turning the axial system results from thickening of the oil, which must be replaced. To do this the instrument is dismantled and the old lubricant is removed from the parts of the axial system by carefully wiping with a cloth lightly moistened with aviation gasoline and then with a clean dry cloth. The parts of the axial systems are then lubricated with oil (see Section 38) and the theodolite is reassembled and adjusted.

Jamming may occur in the vertical axis system as a result of careless assembly during repair or as a result of dirt getting between the parts. This kind of trouble can be corrected only under factory conditions.

In correcting defects in the axial systems, or in replacing the horizontal and vertical dials and other parts, theodolite ThB is usually dismantled only as much as necessary.

Procedure for dismantling the lower part of the theodolite

Remove the baseplate, releasing the lock, remove the optical plummet and the carrier by releasing the three knurled screws and unturning slightly; undo the three screws with the red heads which secure the dial cover to the theodolite stand; carefully remove the lower part of the theodolite (carrier with dial casing) from the stand, taking care not to damage the dial and prisms (see Figs. 60, 61); withdraw the vertical axis thrust bearing (see Fig.59); withdraw the spring with the half rings 3 (see Fig.61); remove the dial sleeve with the dial and pinion (Fig.62); undo the three screws which secure the vertical axis main bearing to the dial casing and withdraw it (see Fig.59).

If the vertical axis (Fig.60) is undamaged do not dismantle it.

The sequence for reassembling the lower part of the theodolite is the opposite of that described.

Procedure for dismantling the upper part of the theodolite (telescope and horizontal axis).

Undo the screw which secures the base to the plate on which the optical micrometer and dial selector prism are mounted; remove the optical micrometer from the instrument (see Fig.63); remove the telescope adjusting screw 25 and the contact level adjusting screw 26; undo the screw and remove the casing of the contact level; remove the prism from the condenser 15 (Fig.48) of the contact level; unscrew the contact level regulating screw; unscrew the three screws which secure the level bracket to the stand and remove the contact level; unscrew the four screws which secure the electric lighting switch 17 to the stand (Fig.47), remove the electric lighting switch and the base of the lower cover 42 (Fig.47); undo the screws and remove the cover of the left-hand upright of the stand (with position CL); undo the screws on the base of the electrical plug socket; undo the screws of the clamp shank of the vertical dial alidade and remove it; undo the screws in the cover of the vertical turntable housing; undo the two screws of the bearing limiting bush (the bearing limiting bush is located in window 8 of Fig.57); unscrew the four screws which secure the vertical dial housing to the base, the opening for which is shown in Fig.68 with the frame of the vertical turntable removed; undo the two screws and remove the unit (for location of unit B see Fig.68) in which are seated the prisms 37, 38 (Fig.54) which transmit the images of the graduations of the vertical dial to the objective of the vertical dial microscope; remove the base of the vertical dial alidade 49 (Fig.68); unscrew the screws which secure the bearing bush to the turntable bearing and remove the bush; undo the two screws of the contact system A (Fig.68) and remove it; undo the three screws with red heads which secure the horizontal dial housing to the frame and remove the lower part of the theodolite together with the housing and the dial; undo the screws which secure the objective mounting of the vertical dial microscope to the stand; remove the vertical turntable housing, shifting the seating of the objective of the vertical dial microscope somewhat (Fig.68 shows the alidade part of the vertical dial with the vertical turntable housing removed); unscrew the screws of the vertical dial sleeve and remove the sleeve from the vertical dial; undo the screws which secure the telescope clamp and remove the clamp; carefully separate the telescope and the horizontal axis from the right-hand upright of the stand (Fig.70); remove the cover of the vertical turntable housing from the horizontal axis, releasing the six screws; unscrew and remove the reading microscope pressing on the catch 51 (Fig.49); undo the screws of the cover and through the hole 7 (Fig.57) undo the screws, and withdraw the mounting with the prism of the reading microscope; undo the three screws and remove the shackle which fixes the telescope to the reading microscope; remove the metal mirror, undoing the three screws in its head; unscrew the ring which secures the back-sight first undoing the lock; undo the screw 6 (Fig.58) which secures the telescope to the horizontal axis; withdraw the telescope from the horizontal axis. This completes the dismantling of the upper part of the theodolite which is necessary in order to correct the defects in the horizontal axis system. The upper part of the theodolite is re-assembled in the reverse sequence to that described.

Since the horizontal axis is the most complicated to dismantle for repair the disturbance of the adjustment may be more serious.

In dismantling and assembling the lower part of the theodolite it is sufficient to make a check(of the location of the place at which the graduations coincide, of the run and parallax in the horizontal dial microscope) but on dismantling and assembling the upper part of the theodolite (the telescope and horizontal axis) the theodolite must be completely readjusted.

## 60. Repair of optical micrometer

The optical micrometer can be dismantled, for repair of any defects which may have been noted, only in a workshop or factory. Faults associated with the adjustment of the optical micrometer are corrected on the basis of the instructions given above. If spare parts are available they can be replaced.

The most complicated optical assembly is the separating prism unit. If any of the cementing in the unit has come adrift the recommendations made above must be followed.

If the slider 3 (Fig.63) is not running smoothly, dismantle the micrometer and check the guide 2. If dirty, the guide 2 and the slider 3 must be carefully cleaned. If there are deep scratches or scoring on the surfaces of the guide or slider they must be carefully removed with a scraper; the parts must then be carefully cleaned and lightly lubricated with watch oil.

Crossing of the micrometer scales is corrected in the following way: release the four screws which secure the arm which presses on the micrometer scale and set the scale. Check the accuracy of setting of the micrometer scale in the instrument.

### 61. Replacement of horizontal and vertical dials

Replace the horizontal and vertical dials if they become cracked or otherwise damaged by accident. To replace the horizontal dial the lower part of the theodolite must be dismantled, and to replace the vertical dial the upper part must be dismantled. The dismantling procedure is described above.

After the horizontal or vertical dials have been removed, wash their seatings in aviation gasoline and wipe them carefully. Fit them by the procedure described above. After the dials have been fitted, assemble and adjust the optical systems of the horizontal and vertical dial microscopes (focus, correct parallax, run, etc.).

## Chapter 9

## CARE OF HIGH PRECISION OPTICAL THEODOLITES TYPES OT-02 AND ThB DURING FIELD WORK

### 62. Preliminary examination of instrument when packed in case or box

Precision optical theodolites types OT-02 and ThB are complicated mechanisms which contain a large number of optical parts, all of which occupy definite positions in relation to one another. Damage or displacement of any of the optical parts and also of some of the mechanical assemblies and parts (adjusting screws, micrometer knobs, etc.) that may result from shocks, or dropping the instrument, can make it unsuitable for use, or impair the accuracy of the readings. Field-workers must therefore know the rules for looking after precision optical instruments.

When the instrument is received, become familiar with the method of packing it into its box or case, study the method of fixing the instrument with the clamping devices and the location of all the parts in the corresponding sockets.

Theodolite OT-02 is packed into a metal case. Before packing, examine the base of the case and its fixing to the cover. On the case base there are sockets for spare telescope eyepieces. The telescope is fixed with the objective upwards (Fig.71), and the centering plate and box with accessories are packed in a separate case (Fig.72).

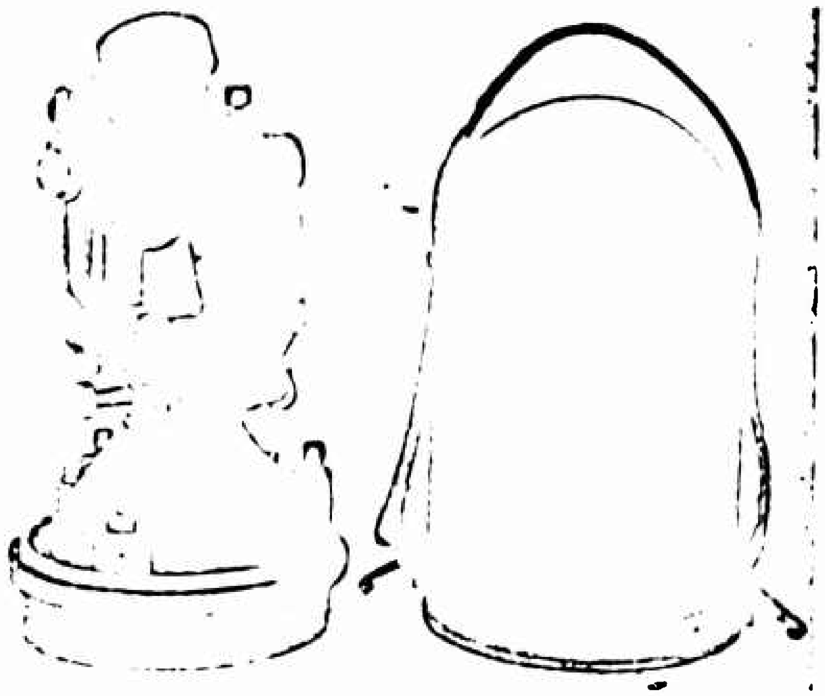

Fig. 71. Theodolite 01-02 on the base of its metal carrying box

Theodolite ThB is packed in a box (Fig.73), and, in packing, the upper part of the instrument is put in relative to the carrier in such a way that the red marks 3 (Fig.46) are one under the other; the telescope is fixed in such a way that the eyepiece is in the upper position and the telescope centre-line is parallel to the vertical axis of the instrument.

If, when the theodolite has been packed, the box cover can be freely closed, the instrument has been correctly placed, but if it is difficult to close then the instrument has been put in incorrectly. When the instrument is taken from the box or put into it the box must be kept lid uppermost because the theodolite and certain accessories which are in the box are not secured.

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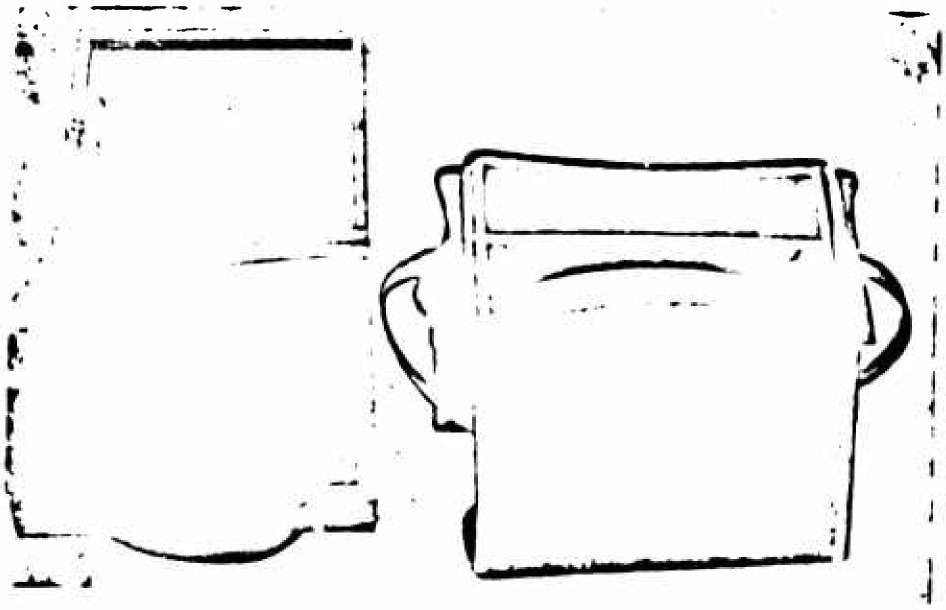

Fig. 77. Carrying case for centering plate and box with accessories for theodolite OT-02

## 63. Transport of optical theodolites

Optical theodolite OT-02 (in its case) and theodolite ThB (in its box) must be looked after during transport. The case with theodolite OT-02 should be kept bottom downwards, and the box containing theodolite ThB with the handle upwards. Soft articles must be packed underneath the case or box to minimise shock. For transport by truck or train, in addition to the boxes and cases described, optical theodolites should be packed in special transport boxes which contain soft packing.

In packing for horse transport, theodolite OT-02 in its case and theodolite ThB in its box, are wrapped in canvas and tied to one side of the horse. A similar counterweight of some kind should be secured to the other side of the horse. In places where passage is dangerous the instrument should be removed from the horse and carried. The condition of the case or the box and also of the transport box should always be carefully examined.

Fig. 73. Theodolite ThB in box

When optical theodolites are removed from a cold to a warm room, or vice versa, they must be left closed for three or four hours (type OT-02 in its case and ThB in its box) before use. The box or case containing the instruments should not be put near heating equipment.

When carrying the box with theodolite ThB or the case with theodolite OT-02, use the straps of the box or the shoulder carrier for the casing of theodolite OT-02.

## 64. Moving optical theodolites to an observation station

As optical theodolites are light in weight, and small in size, it is much easier to move them to an observation station than theodolites type TT 2"/6". When carrying theodolite OT-02, the case with the theodolite is secured on a shoulder carrier and the box with theodolite ThB on a shoulder strap. The observer should personally supervise the carrying of optical theodolites to the station.

The following rules must be observed whilst optical theodolites are at the station. If intervals between observations are comparatively long, the theodolite should be packed in the box or case. The box of theodolite ThB or the case of theodolite OT-02 should be covered with a canvas cover and tied to the observation station table with a cord. The theodolite should not be left on the station table overnight or without supervision.

## 65. The care of optical theodolites in use

The procedure for setting up an optical theodolite on the observation station platform is as follows: centre above the datum point and firmly press the three feet of the centering plate into the table. Then put the setting plate on it and screw up tight. Place the theodolite ThB in its slot and secure the lock. To transfer theodolite ThB take the carrier in one hand and hold the base in the other.

Theodolite OT-02 is mounted on the centering plate by screwing the theodolite, together with the setting plate, on to plate. Carry theodolite OT-02 by taking the setting plate in one hand and supporting the stand in the other.

In setting the optical theodolite the vertical axis of the instrument must immediately be brought to the vertical position, at least approximately.

The instrument should be cleaned of dust every day after finishing work, the ends of the screws and sleeves should be lightly oiled and all the micrometer screws returned to the centre of the threads. If the weather is wet and atmospheric conditions unfavourable, all parts which are not painted or lacquered should usually be covered with oil or vaseline.

If the instrument is standing on the station table or on its tripod between operations, it must have its cover on.

### 66. Care of optical parts

Optical parts must be protected against damage. When working with optical theodolites the lenses must not be taken out of their mounts or the telescope objective unscrewed. If the eyepiece is exchanged during the course of the work this should be done quickly and carefully so that no dust gets on the graticule.

The outer surfaces of the lenses of the telescope objective, eyepieces, etc., may be wiped with a special old white linen cloth which has been washed without soap, or with a fine linen cloth. Clean cotton wool moistened with alcohol may be used provided great care is taken that the alcohol does not get inside, since it dissolves the balsam with which the lenses and other optical parts are cemented.

## 67. Care of the axial systems of optical theodolites

Care in transportation is the principal means of preventing damage to the axes of precision optical theodolites. It is not possible under field conditions to correct defects in the axial systems, this must be done in the workshop or by the factory.

## APPENDIX 1

### Determination of focal length

There are various methods of determining focal lengths. For example, by using a telescope of known focal length set to infinity. For this purpose, a plate carrying two lines is set in the focal plane of the collimator at its known focal length in such a way that the two lines are symmetrical about the optical axis. The distance between the lines should be measured accurately on a comparator or on a universal microscope.

The system to be tested is set on the collimator axis. The distance $y$ between the images of the lines is measured by means of an eyepiece provided with an optical micrometer or by an eyepiece micrometer of known calibrations. We then have the equation

$$y:y' = f_1:f_2,$$

from which we determine

$$f_1 = \frac{y}{y'} f_2, \qquad (30)$$

where $f_2$ is the focal length of the collimator; $y'$ the distance between the lines on the plate located at the collimator focus, and $f_1$ is the focal length of the system under test.

In formula (30) the quantity $\frac{f_2}{y'} = k$ is constant for a given collimator. Determination of focal lengths of systems is therefore simplified; it consists in measuring the quantity $y$ and calculating by the formula $f_1 = y \times k$.

<u>Determination of focal length of the objective by the variable magnification method</u>

Special Zeiss and Bamberg focus meters exist for measuring the focal lengths of an objective by this method but it is also possible to use a simple Zeiss measuring microscope or an instrument microscope with various attachments.

Determination of the focal length of a system by the variable magnification method is based on determining the magnification for several, and, at any rate, more than two different positions of the object (scale) which is on the principal axis of the system under test. Here, the distance between the positions of the object and the system under test (lens objective) should be known.

The position of the object (object scale) is altered by means of a ring of thickness $d = 20$ mm, which is placed under the objective and, in measuring focal lengths of lenses, by means of a ring of thickness $d_1 = 5$ mm.

Six pairs of rings are prepared for the microscope (diameters of 10, 15, 20, 30, 40 and 50 mm) so that it is possible to measure focal lengths of objectives and lenses of diameters up to 50 mm and focal lengths up to 300 mm.

Moreover, a millimetre scale is marked on the microscope table, or a separate scale is used. Before starting the measurements the objective to be tested is set in such a way that the visual axis of the microscope passes through the centre of the objective and coincides with its optical axis. For this purpose, the microscope is focussed on a table with a scale and the graticule cross is brought to the middle of the central graduation of the scale. Then the objective(or lens) to be tested is carefully placed in such a way that the image of this graduation occupies the previous position on the graticule. After this, the table is moved 2 - 3 mm away from the centre by the micrometer screw (by an amount equivalent to the entire free diameter of the system tested) making up to three readings at each point of the scale. This is repeated with the objective in a second position when it is set on a ring of d = 20 mm and the same graduations are observed as in the first position.

The mean of three readings is taken. The difference between the readings between symmetrical graduations on the scale is the size of the images $y_1'$ and $y_2'$, and the difference between the readings between the corresponding graduations on the scale is the size of the object $y_1$ and $y_2$ (Fig.74).

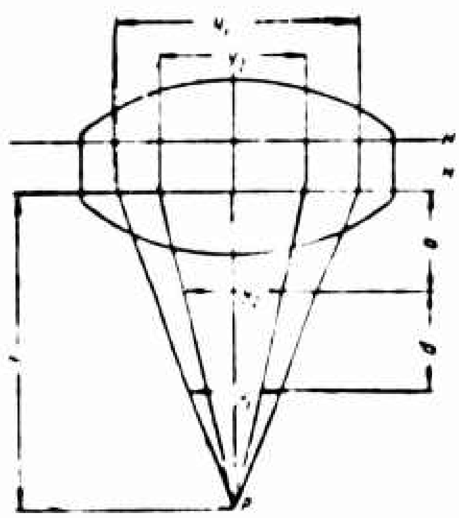

Fig. 74.

Taking the ratios $\frac{y_1'}{y_1}$ and $\frac{y_2}{y_2'}$, and substituting their values in the formula

$$f = \frac{d}{\frac{y_2}{y_2'} - \frac{y_1'}{y_1}},$$

we find that $f$ is the focal length of various zones of the system.

If the difference between different zones is insignificant i.e., the system is almost without aberration, and $f_{av}$ is taken as the mean of all the values by zones.

## APPENDIX 2

### Measuring the refractive index of a lens

The refractive index of a lens may be measured in two ways: (1) without altering the shape of the lens (immersion method) and (2) by making two flats on the free periphery of the lens. The refractive index can be measured by either method without damaging the optical system, i.e., the lens can be replaced in the instrument.

In the first method a vessel with plane-parallel sides is filled with a mixture of liquids which is selected in such a way that its refractive index can be altered by adding one of the components of the mixture, for example, kerosine and alpha-monobrome naphthalene.

The vessel is set up between two telescopes set to infinity, one of which serves as a collimator. In the focus of this one a mirror is placed which is observed in monochromatic light. When the test lens is placed in the vessel the image of this mirror becomes blurred. One or other of the liquid components is added to alter the refractive index of the mixture until the image becomes sharp again, then the refractive index of the mixture is equal to that of the test lens. The refractive index of the liquid is measured on a Pulfrich refractometer, not forgetting that the refractive index of the liquid is very temperature sensitive. The advantage of this method is that the lens is completely undamaged, its disadvantages are (a) a great deal of time is required to adjust the mixture, (b) it is very difficult to hit on the instant when the refractive indices of liquid and lens are equal and (c) it is not very accurate (third place of decimals).

The second method consists essentially in measuring the refractive index of a prism and, therefore, the procedure is just the same as is used in measuring the refractive index of prisms and is described below.

(1) Measurement of the refractive index of the lens by the minimum angle of deflection

Two flats are made on the free periphery of the lens in such a way that the angle $\varphi$ between the planes of the flats is about $60^{\circ}$ (Fig.75).

The planes of the flats should be parallel to the optical axis of the lens and the quality of the surfaces must be good, because if they are not parallel it is very difficult or even impossible to secure auto-collimation images from these planes; if the quality of the surfaces is poor the auto-collimation images are weak and blurred.

In this method the lens is set in wax on the table of a precision spectrometer. An auto-collimation image of the slot must be obtained in the auto-collimation eyepiece of the spectrometer telescope. This image should be on the level of the plane of the flats. The angle of refraction is measured at 5 different positions of the dial (Table 9).

Having determined the refractive angle, the minimum angle of deflection $\delta$ is measured for tho lines C, D and F. A slot is set up in the focus of the spectrometer collimator. The auto-collimation eyepiece in the telescope is replaced by a micrometer eyepiece in which the magnitude of the bisector may be altered depending upon the width of the slot.

The slot is illuminated with monochromatic light; a Geissler hydrogen tube is used for the lines C and F and with a sodium burner or a spirit lamp with its wick impregnated with salt for line D .

The minimum deflection $\delta$ is determined as follows. The telescope is first aimed directly at the collimator slot and a reading is made on the dial (Tables 10, 11 and 12). Then, by naked eye, the image of the slot is observed through the lens, the telescope is brought up and the spectrometer table with the lens is turned, and the displacement of the image of the slot is observed through the telescope; the image moves in the same direction as the lens until at a certain instant the image of the slot stops and begins to move in the opposite direction to the table (Tables 10, 11 and 12).

This position is that of the minimum deflection and, the telescope is aimed at the image of the slot and a reading is taken on the dial. Measurements are again taken in five positions (Tables 10, 11 and 12).

Having determined the refraction angle $\alpha$ and the minimum deflection angle $\delta$ for the lines C, D and F , the refractive index is calculated by the following formula:

$$n = \frac{\sin\frac{\varphi+\theta}{2}}{\sin\frac{\varphi}{2}}.$$

This is a very accurate method and if the flats are carefully prepared an experienced operator can determine the refractive index to the fourth decimal place.

The results of measurements given in Tables 9, 10, 11, and 12 show that the lens in question was made of glass K-8.

(2) Measurements of the refractive index of a lens by the reflection method

In this method the measurements are made on a goniometer without a collimator and with one auto-collimation telescope. The essentials of the method are as follows. Light which enters the lens is reflected at a right angle from the surface of the second flat and turns back upon itself (Fig.76).

There is a slot at the focus of the telescope objective. Light which leaves it becomes parallel on leaving the objective and after refraction through the first flat on the lens reaches the plane of the second flat. Here it is partly reflected and partly transmitted outside the lens. Since only the reflected light is used in the observation, the second flat may be silvered to improve the reflection.

The reflected light is refracted through the first surface of the flat and is focussed in the focal plane of the telescope objective to give an image of the slot which, depending upon the position of the reflecting flat, may lie either to the right or to the left of the slot and either in front of or behind it.

The lens position can be adjusted until the incident rays are perpendicular to the plane of the second flat. Then the reflected rays pass back in the previous direction and the image of the slot coincides with the slot. The angle of incidence of the light on the lens is equal to the return angle of reflection. The equation for calculating the refractive index is obtained from the expression: $n=\frac{\sin\alpha}{\sin\alpha'}$

by substituting the quantity $\varphi$ for $\alpha'$, i.e. $n=\frac{\sin\alpha}{\sin\varphi}$.

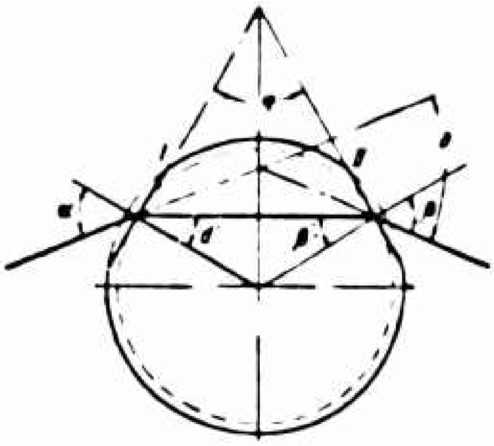

Fig. 75.

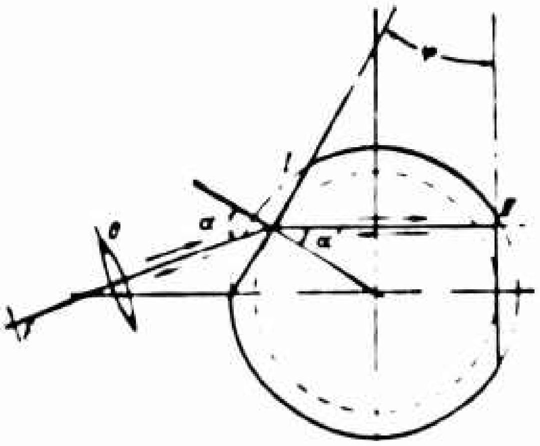

Fig. 76.

Table 9

Measurements of angle of refraction $\varphi$

| No of reading | Readings taken whilst observing the flats | | | | | |
|---|---|---|---|---|---|---|
| | I | | | II | | |
| | Microscope A | Microscope B | Mean | Microscope A | Microscope B | Mean |
| I | 25°59'30" | 205°59'39" | 25°59'34" | 264°12'09" | 84°12' 9" | 264°12'09" |
| II | 5 31 36 | 185 31 39 | 5 31 37 | 243 44 18 | 63 44 17 | 243 44 17 |
| III | 340 11 40 | 160 11 38 | 340 11 39 | 218 24 18 | 38 24 18 | 218 24 18 |
| IV | 311 57 29 | 131 57 25 | 311 57 27 | 190 10 07 | 10 10 04 | 190 10 05 |
| V | 282 32 35 | 102 32 35 | 282 32 35 | 160 45 12 | 340 45 14 | 160 45 13 |

$\varphi'_{a} = I - II = 121°47'22"$

$\varphi = 180° - \varphi'_{a} = 180° - 121°47'22"$

$\varphi = 58°12'38"$

$\frac{\varphi}{2} = 29°06'19"$

Table 10

Measurement of angle $\theta$ for line C

| No of reading | a | | | b | | |
|---|---|---|---|---|---|---|
| | Microscope A | Microscope B | Mean | Microscope A | Microscope B | Mean |
| I | 359 57 08" | 179°57'16" | 359 57'12" | 323°19 31" | 143°19'31" | 323°19'31" |
| II | 359 57 12 | 179 57 19 | 359 57 16 | 323 19 26 | 143 19 27 | 323 19 27 |
| III | 359 57 11 | 179 57 17 | 359 57 14 | 323 19 22 | 143 19 25 | 323 19 24 |
| IV | 359 57 09 | 179 57 19 | 359 57 14 | 323 19 26 | 143 19 27 | 323 19 26 |
| V | 359 57 12 | 179 57 16 | 359 57 14 | 323 19 28 | 143 19 28 | 323 19 28 |

Mean 359°57'14" Mean 323°19'27"

$\theta_C = a - b = 36°37'47"$

Table 11

Measurement of angle a for line F

| No of reading | a | | | b | | |
|---|---|---|---|---|---|---|
| | Microscope A | Microscope B | Mean | Microscope A | Microscope B | Mean |
| I | 359°57′12″ | 179°57′19″ | 359°57′16″ | 322°39′26″ | 142°39′29″ | 322°39′27″ |
| II | 359 57 10 | 179 57 18 | 359 57 14 | 322 39 33 | 142 39 34 | 322 39 34 |
| III | 359 57 11 | 179 57 15 | 359 57 13 | 322 39 30 | 142 39 33 | 322 39 31 |
| IV | 359 57 12 | 179 57 18 | 359 57 15 | 322 39 32 | 142 39 36 | 322 39 34 |
| V | 359 57 13 | 179 57 19 | 359 57 16 | 322 39 32 | 142 39 34 | 322 39 33 |

Mean 359°57′15″ Mean 322°39′32″

$\theta_F = a - b = 37°17'43''$

Table 12

Measurement of the angle a for line D

| No of reading | a | | | b | | |
|---|---|---|---|---|---|---|
| | Microscope A | Microscope B | Mean | Microscope A | Microscope B | Mean |
| I | 359°57′10″ | 179°57′17″ | 359°57′13″ | 323°06′40″ | 143°06′46″ | 323°06′43″ |
| II | 359 57 12 | 179 57 13 | 359 57 15 | 323 06 40 | 143 06 46 | 323 06 43 |
| III | 359 57 13 | 179 57 17 | 359 57 15 | 323 06 41 | 143 06 43 | 323 06 42 |
| IV | 359 57 14 | 179 57 18 | 359 57 16 | 323 06 42 | 143 06 46 | 323 06 44 |
| V | 359 57 11 | 179 57 15 | 359 57 13 | 323 06 43 | 143 06 53 | 323 06 48 |

Mean 359°57′15″ Mean 323°06′44″

$\theta_D = a - b = 36°50'31''$

$$n_D = \frac{\sin\frac{\theta_D + \varphi}{2}}{\sin\frac{\varphi}{2}} = \frac{\sin 47°31'34''}{\sin 29°06'19''} = \frac{0,737585}{0,486416} = 1,51636$$

$$n_F = \frac{\sin\frac{\theta_F + \varphi}{2}}{\sin\frac{\varphi}{2}} = \frac{\sin 47°45'10''}{\sin 29°06'19''} = \frac{0,740251}{0,486416} = 1,52185$$

$$n_C = \frac{\sin\frac{\theta_C + \varphi}{2}}{\sin\frac{\varphi}{2}} = \frac{\sin 47°25'13''}{\sin 29°06'19''} = \frac{0,736337}{0,486416} = 1,51380$$

$$n_F - n_C = 0,00805.$$

The requirements concerning the preparation of the flats are the same as for the method of minimum angle of deflection of the light. The angle between the flats should not be greater than the angle of total internal refraction, so it should be between 20 and 30°.

Measurement of the refractive index consists in measuring the angles $\varphi$ and $\alpha$ . The method of setting the lens is the same as in determining the refractive index by the minimum angle of deflection. The angle $\varphi$ is measured in the usual way, and the angle $\alpha$ is measured as follows: By means of an auto-collimation eyepiece the telescope is set up perpendicular to the surface of the first flat and the dial is read. Then the telescope is turned (in some constructions of goniometer the dial is turned and the telescope is stationary) until the image of the slot reflected by the surface of the second flat coincides with the actual slot and again a reading is taken on the dial. The difference between the readings gives the angle $\alpha$ . The accuracy of determination of refractive index by this method depends on the quality of the flats and the experience of the operator.

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