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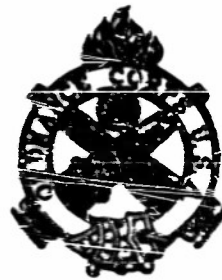
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FRANKFORD ARSENAL

REPORT NO. R-1130



EXAMINATION AND EVALUATION OF FOREIGN FIRE CONTROL MATERIEL

SOVIET AIMING CIRCLE

BY

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R. T. COOK

ORDNANCE PROJECTS 771-10550
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FIRE CONTROL PROJECT 417

Fire Control Instrument Group

FRANKFORD ARSENAL

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MAY 1953

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**EXAMINATION AND EVALUATION OF
FOREIGN FIRE CONTROL MATERIEL
SOVIET AIMING CIRCLE**

**ORDNANCE PROJECTS TR1-1055D
TB3-0035**

FIRE CONTROL PROJECT 417

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1953**

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EXAMINATION AND EVALUATION OF FOREIGN FIRE CONTROL MATERIEL

SOVIET AIMING CIRCLE

OBJECT

A Soviet Aiming Circle, having certain similarities to the Aiming Circle M1, was forwarded to this Arsenal by the Office, Chief of Ordnance. The Ordnance Corps was interested in learning whether the instrument has any desirable features which could be utilized in current development projects.

SUMMARY

A complete investigation of the optical and mechanical characteristics of the Soviet Aiming Circle was made. Mechanical operating features were observed and measured at low (-65° F) and high (+160° F) temperatures, and comparisons of these were made with similar determinations at room temperature. The effect of shock and vibration conditions on the mechanical accuracy of the instrument was also investigated. In general, only minor differences were found between the optical characteristics and the mechanical features of the Soviet Aiming Circle and the U.S.A. Aiming Circle M1. Shock and vibration conditions were found to have little effect except for considerable backlash and deviation from plumb travel which developed in the elevation mechanism. At -65° F the operation of the instrument was somewhat rougher than at room temperature, but the operation was not severely impaired.

The most notable design features of the Soviet Aiming Circle have been known to American designers; in some instances they have been used in our own instruments. For example, the azimuth scales now employed on the Panoramic Telescope M1 are similar to those found on the Soviet Aiming Circle. Furthermore, non-linear range scales, such as are included in the Soviet Aiming Circle telescope reticle, are now utilized as vertical range scales on some American binoculars.

Small samples of the lubricants used in the Soviet Aiming Circle were analyzed. Although a complete analysis could not be made because of the small samples quantities, results indicate that a thorough analysis of these materials should be made. Except for a graphite filler in the grease used on worms and gears of the instrument, none of the components of the lubricants could be positively identified. It is possible that the lubricants are composed of some material that has been developed outside of our knowledge. This possibility warrants further investigation.

AUTHORIZATION

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SOVIET AIMING CIRCLE

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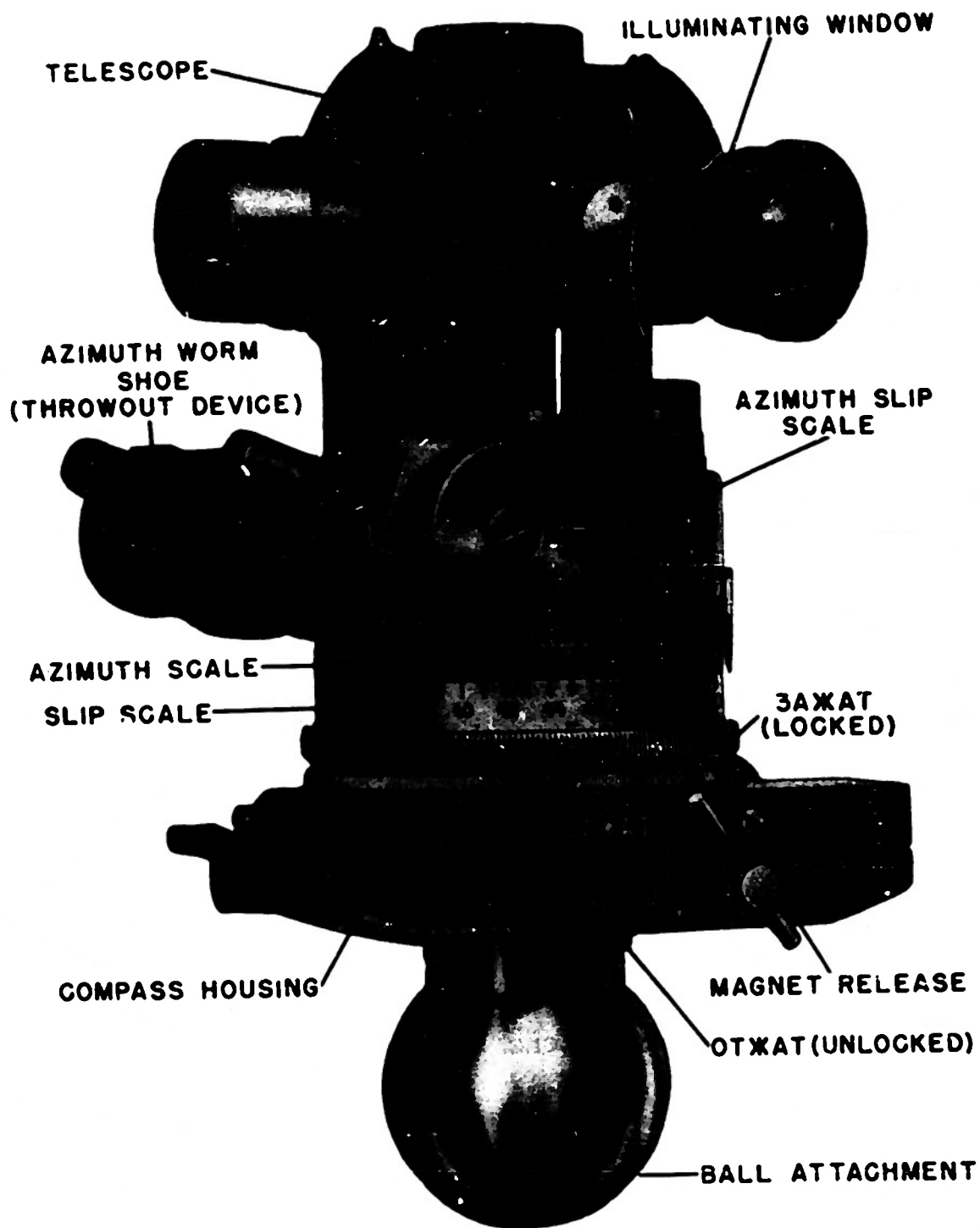


Figure 1. Soviet Aiming Circle
Objective View

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EXAMINATION AND EVALUATION OF

FOREIGN FIRE CONTROL MATERIEL

SOVIET AIMING CIRCLE

I INTRODUCTION

At the request of the Office, Chief of Ordnance, a study of the Soviet Aiming Circle was made by the Experimental Division, General Engineering Department, FCIG. The purpose of the study was to ascertain any desirable features of the instrument which could be utilized in current development projects.

This report is a digest of the results of this study, and based upon these observations, an evaluation of the various parts of the instrument has been made wherever feasible. Throughout the investigation, wherever possible, direct comparison has been made between the Soviet Aiming Circle and the U.S. Aiming Circle M1 (See U.S. Army Specification 51-71-25, dated 28 July, 1937).

The results and discussion are described under the following sub-sections:

1. Basic differences between the Soviet Aiming Circle and the U.S. Army Aiming Circle M1.
2. A resume of the optical characteristics of the sighting telescope, including a complete evaluation of the reticle scales.
3. Analysis of the mechanical features, including the effects of low temperatures, high temperatures, and vibration and shock.
4. Determination of compass sensitivity and precision of orientation to magnetic north.
5. Determination of sensitivity of the leveling device.
6. Analysis of the lubricants.

The various components of the Soviet Aiming Circle are shown in figures 1 to 3, 6 and 7.

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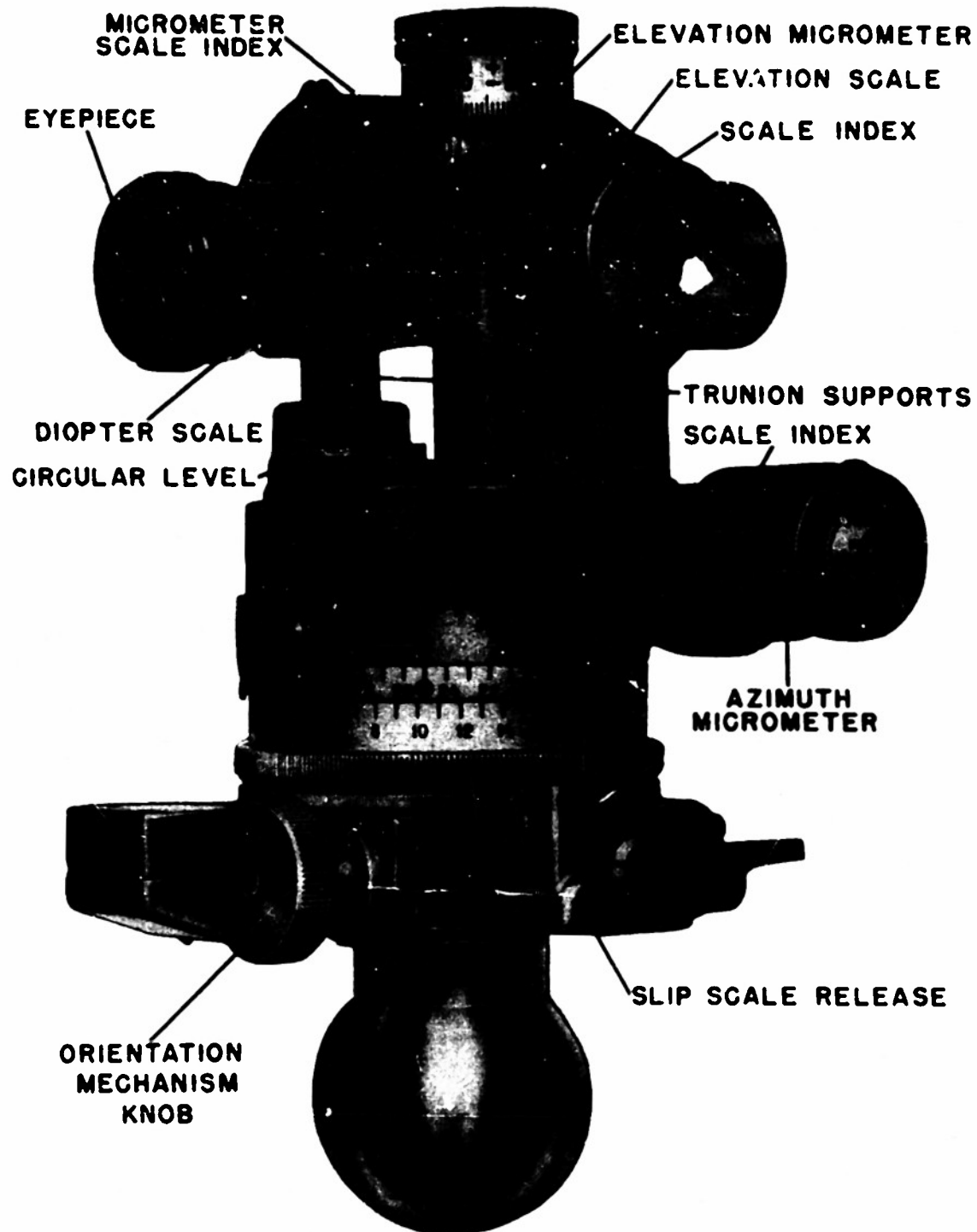


Figure 2. Soviet Aiming Circle
Eyepiece View

II METHODS

A. ANGULAR MEASUREMENT

The evaluation of the instrument required the measurement of angles to a precision greater than that provided by the instrument itself. In the investigation of the characteristics of the Soviet Aiming Circle, the principal instrument used for measurement of the angle was the precision Theodolite, Model T3, manufactured by Henry Wild Surveying Instruments Co., Heerbrugg, Switzerland. The Wild Theodolite provides for measurement of angles down to two-tenths of a second of arc with such accuracy that the "closing-error" of triangles in actual practice is in the range 0.8 to 0.9 seconds. As the use of the Aiming Circle requires accuracy only of the order of the mil (a unit equivalent to more than 3 minutes of arc), the Wild Theodolite provides accuracy in angular measurement far in excess of that required. Consequently, for the measurements in which it was utilized, the Theodolite was not used to its full limit of precision, but rather depending on the particular measurement to an accuracy lying between 10 seconds and 1 minute of arc.

B. ENVIRONMENTAL CONDITIONS

Environmental test on the Soviet Aiming Circle consisted of exposure at temperatures of -65°F and $+160^{\circ}\text{F}$ for two days each. Observations of mechanical operation characteristics were made under these conditions for comparison with room temperature data.

C. SHOCK AND VIBRATION

To facilitate the description of vibration and shock tests, the directions of three principal axes relative to the instrument are defined. In Figures 1 and 2, the X-axis is the one passing through the cylindrical portion of the body of the instrument parallel to the axis of the telescope and the long dimension of the compass housing. The Y-axis is in the horizontal plane containing the X-axis and is perpendicular to the X-axis. The Z-axis is vertical, mutually perpendicular to the X and Y axes.

Vibration tests were made on L.A.B. Corp. Model VUDM Vibration Test Table. This machine permits vibration either at constant frequency, manually varied frequency or automatically cycled frequency. The frequency range for all three modes of operation is the same, 10 to 55 cycles per second. Amplitudes of vibration are calibrated in steps of $1/32$ of an inch. The Soviet Aiming Circle was subjected to vibration parallel to each of the three principal directions (X, Y, and Z) independently. In each direction two 10-minute periods of vibration were used. In the first, amplitude was set at $1/32$ inch, while frequency cycled automatically in the range from 10 to 55 cycles per second. In the second vibration period, amplitude was increased to $1/16$ inch, while the same conditions of frequency cycling were retained. The time required for one complete cycle of frequency is about 45 seconds. Automatic frequency cycling throughout the range of the vibration machine was used in order to excite resonance vibrations in the various components of the instrument.

Shock tests were performed on the Barry Corporation medium impact shock machine, which is located in the AEE L Branch of the U.S. Naval Air Development Center, Johnsville, Pa. Ten shocks with maximum acceleration of 20 G's ($1\text{ G} = \text{acceleration due to gravity} = 32.2\text{ ft/sec}^2$) were administered in the direction of each of the principal axes, X, Y, and Z. (The direction of the shock is that direction in which the acceleration takes place.)

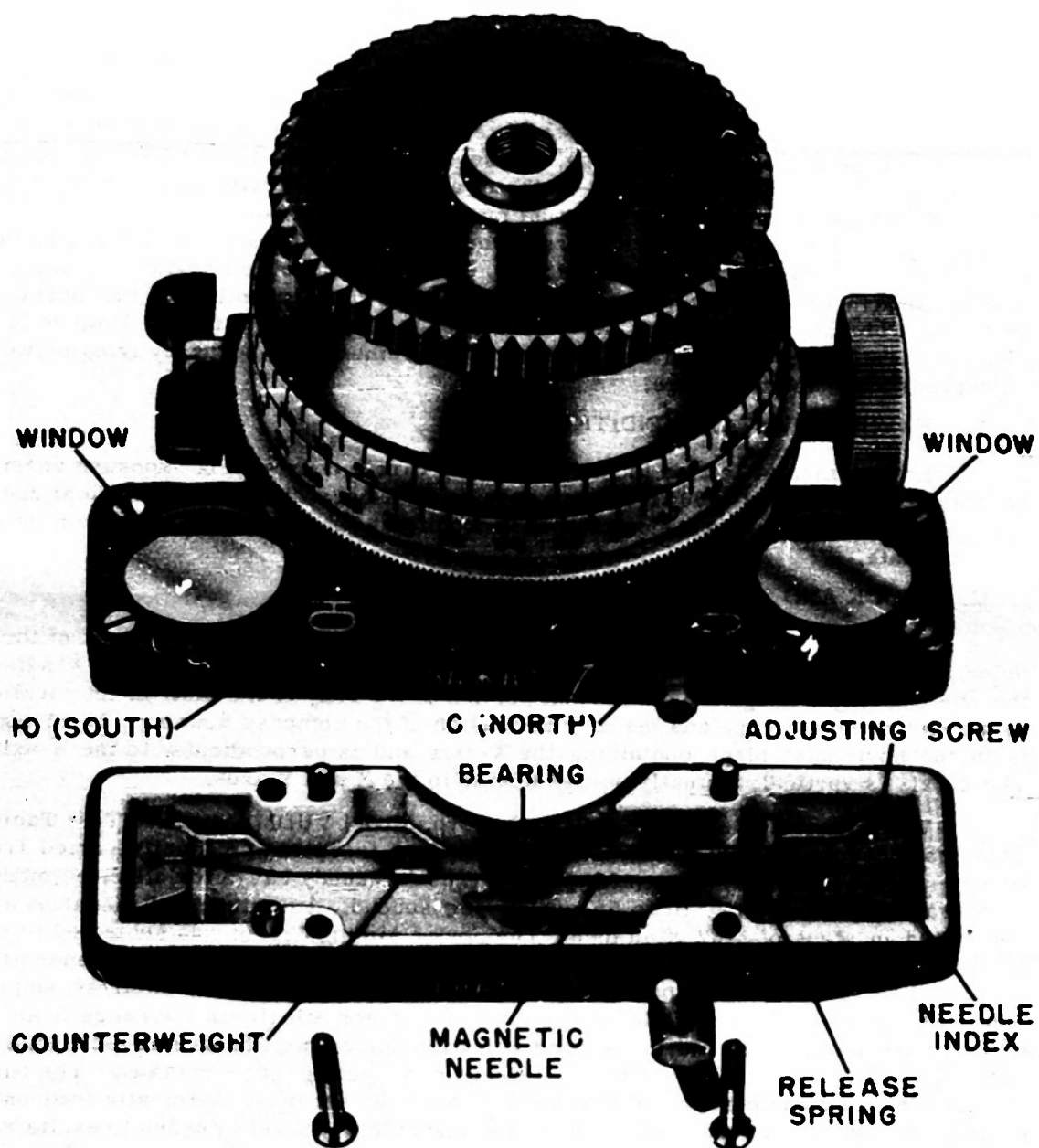


Figure 3. Soviet Aiming Circle
Compass Assembly

III RESULTS AND DISCUSSION

A. BASIC DIFFERENCES BETWEEN THE SOVIET AIMING CIRCLE AND THE U.S. ARMY AIMING CIRCLE M1.

The basic unit of angular measurement used on the Soviet Aiming Circle is 1/6000th part of a circle, as compared with 1/6400th part of a circle for the standard artillery mil. This unit of measurement is identified in this report as the "Russian mil", and is equivalent to 16/15 of our mil. The term "mil" when used means the standard artillery mil; when the "Russian mil" is used, it is so identified.

In addition to the azimuth scale and micrometer incorporated in the Aiming Circle M1, the Soviet Aiming Circle utilizes secondary slip scales in azimuth determinations. The slip scales permit the use of an arbitrary reference line for angular measurement without necessitating continual reference to magnetic north. For differentiation, the regular azimuth scales are marked in black on the instrument; the slip scales are marked in red.

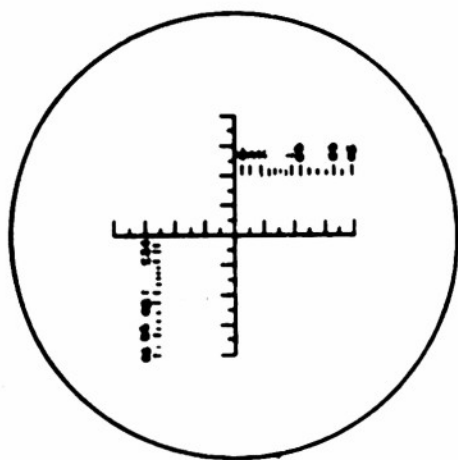
While the Aiming Circle M1 provides a complete circle for the compass dial, the Soviet Aiming Circle uses only a small sector of a circle for this purpose (see figure 3). This allows the needle to oscillate freely only when it is near the proper north-south orientation. However, since this is the principal use of the compass, most of the circle is eliminated to obtain compactness.

Another notable feature of the Soviet Aiming Circle is the angle of site movement. The telescope of the Aiming Circle M1 is fixed to view only in the horizontal plane; the elevation of an object is indicated by its position on the vertical scale of the reticle. On the Soviet Aiming Circle, the telescope may be elevated through a range of approximately 600 Russian mils - 300 on each side of the horizontal position. For the convenience of differentiating inclination and declination readings, two scales are provided on the elevation micrometer (see figure 2). Red (positive) numerals are used to indicate inclination; Black (negative) numerals indicate declination.

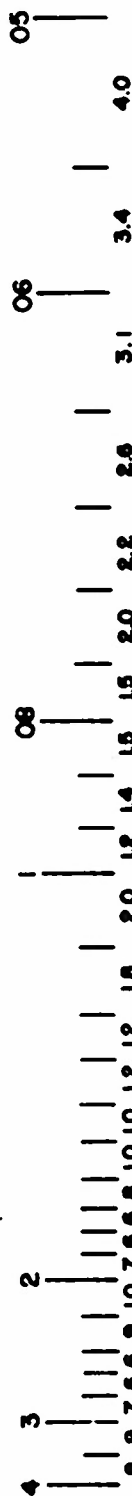
B. OPTICAL SYSTEM

A side-by-side comparison of the optical characteristics of the sighting telescopes of the Soviet Aiming Circle and the U.S. Army Aiming Circle M1 is given in Table I. The power of the telescope is calculated from measured values of the entrance and exit pupils, and is given by the ratio of these two factors. For the Soviet Aiming Circle the entrance pupil was measured as 18.2 mm, and the exit pupil was measured as 3.0 mm. The Aiming Circle M1 was found to have a 16.0 mm entrance pupil and 4.0 mm exit pupil. The axial resolution of the Soviet sight was measured as 7.4 seconds; the calculated theoretical resolution was 6.7 seconds. These values compared favorably with the measured resolution of 8.8 seconds and the calculated theoretical resolution of 7.6 seconds for the Aiming Circle M1.

The field of view of six degrees, 30 minutes for the Soviet Aiming Circle is considerably smaller than the nine degrees, 15 minutes field of the Aiming Circle M1. However, this limitation is not severe, since the smaller field of the Soviet Circle is considered adequate for the uses of the telescope.



(a) COMPLETE RETICLE PATTERN



NOTE: LOWER NUMERALS INDICATE MEASURED ANGULAR INTERVALS BETWEEN DIVISIONS. THESE DO NOT APPEAR ON THE RETICLE.

(b) NON-LINEAR SCALE, ENLARGED.

Figure 4. Telescope Reticle

TABLE I
OPTICAL CHARACTERISTICS

	Soviet Aiming Circle	U.S.A. Aiming Circle M1
Field	6° 30'	9° 15'
Entrance Pupil	18.2 mm	16.0 mm
Exit Pupil	3.0 mm	4.0 mm
Power	6.1	4
Axial Resolving Power	7.4"	8.8"
Theoretical Resolving Power	6.7"	7.6"
Parallax Distance	125-175 yards	75-85 yards

There was no parallax between the image and the reticle divisions of the Soviet Aiming Circle when a target was viewed at distances between 125 and 175 yards. The parallax distance for the Aiming Circle M1 is specified to be from 75 to 85 yards.

The optical characteristics of the telescope were apparently unaffected by either the shock, vibration, or environmental conditions to which the Soviet Aiming Circle was subjected. No internal fogging of the telescope was observed under conditions of either high or low temperature.

The reticle of the Soviet Aiming Circle telescope (see figure 4a) consists of two sets of scales: a linear set of crossed horizontal and vertical graduations, and a non-linear set of horizontal and vertical graduations. The linear horizontal and vertical scales are centrally located in the reticle and extend eight divisions in each direction from the center. Each of these divisions was found to correspond to an interval of five Russian mils, thus allowing variations of up to 40 Russian mils in azimuth or elevation to be determined with the reticle.

The angular interval between divisions on the non-linear scales was measured and is shown on the enlarged scale drawing (see figure 4b). This type of scale is employed in some American binoculars as a vertical range scale. A check of the non-linear scales of the Soviet Aiming Circle reticle showed that they are similarly used in surveying: With the central vertical line of the reticle zeroed on the target, angular measurement to a given number on the scale was taken. The linear ground distance is then $l = d \cot \theta$ (figure 5). When two meters were used as the range batten distance ("d" in figure 5), it was found that the number on the scale represented the linear ground distance required. It should be noted that, while these scales in the Soviet Aiming Circle reticle

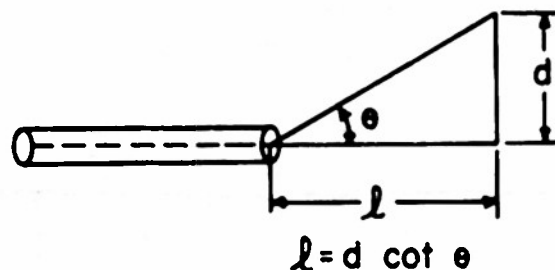


Figure 5. Surveying Relationships

may actually be used in conjunction with a 2-meter batten for surveying, similar scales in American binoculars are used for much cruder range estimations.

For night operation, the reticle of the Soviet Aiming Circle may be illuminated through a small glass window set in the left side of the telescope housing. When it was tested in a darkened room, the figures and graduations of the reticle appeared clearly defined.

C. MECHANICAL SYSTEM

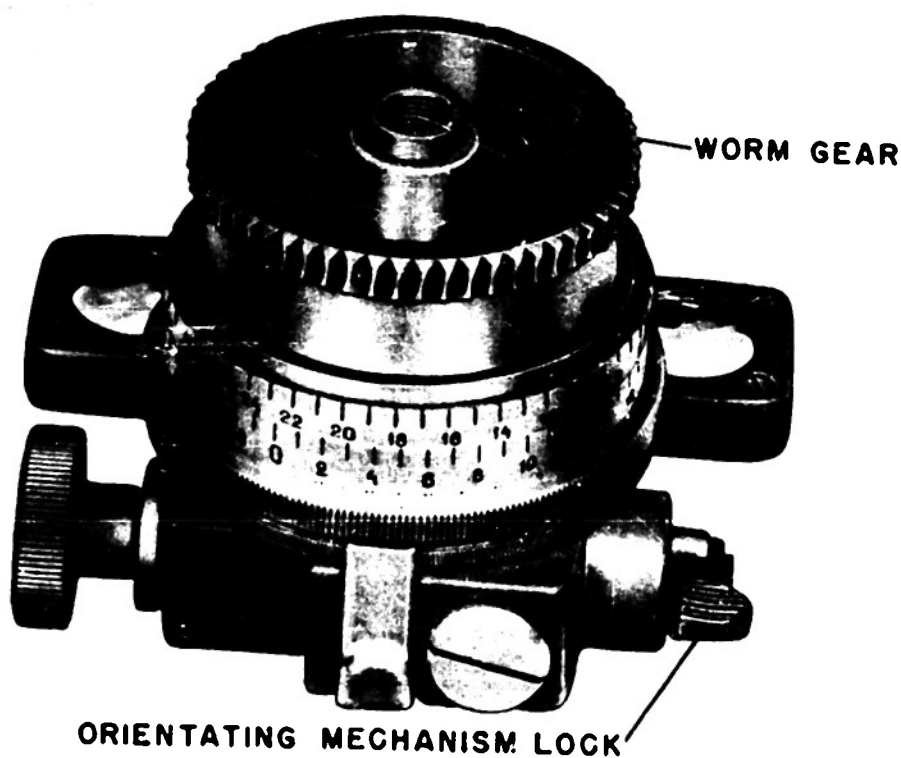
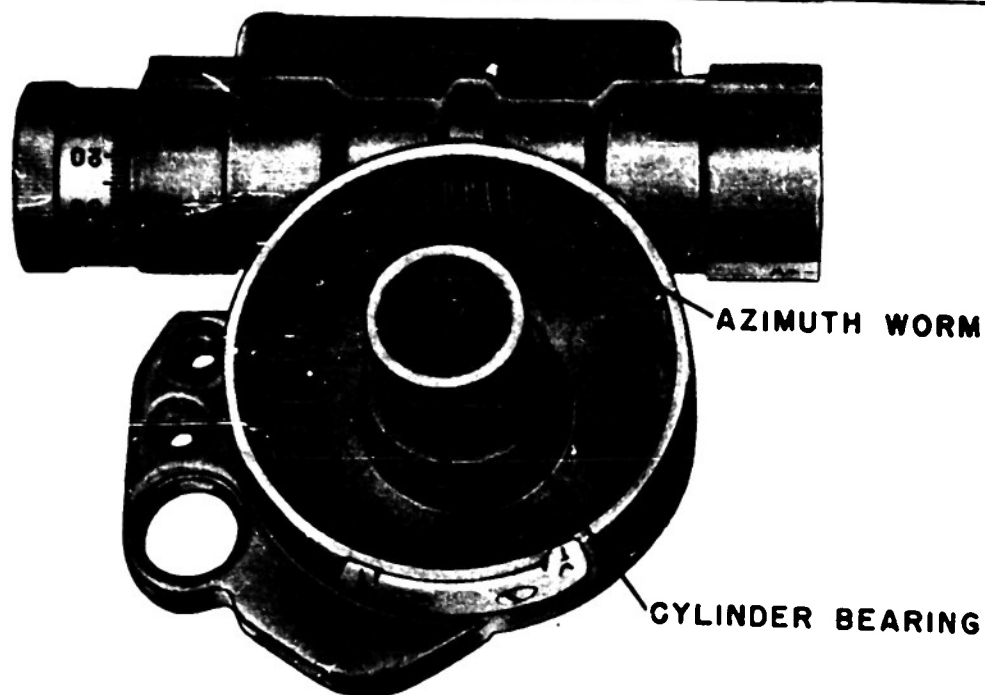
1. Azimuth and Elevation Mechanism (Figures 6 and 7)

The azimuth scale is divided into 60 divisions, each equal to 100 Russian mils. The micrometer knob, which rotates the azimuth gear wheel through a worm drive, is divided into 100 divisions, each of which is equal to one Russian mil (16/15 mil). These scale graduations were found to be uniform to within 0.1 mil. Backlash in the azimuth mechanism amounted to 0.2 mil before the instrument was subjected to vibration and shock conditions. Backlash increased to 0.3 mil after these tests.

The flatness of the azimuthal plane of rotation was checked at intervals of 1000 Russian mils on the azimuth scale. The maximum variation from flatness was found to be 0.2 mil. After shock and vibration tests, the maximum variation from flatness increased to 0.4 mil. Variations of the azimuthal plane of rotation from flatness are shown in Table II.

During observation of azimuth settings the apparent elevation of the target changed when the direction of rotation of the azimuth micrometer knob was reversed. The extent of this change was measured and the values compared with similar observations on the Aiming Circle M1. The effect on the Soviet Aiming Circle was found to be small — 0.1 mil before shock and vibration treatment. After shock and vibration tests, the maximum value of this change in apparent elevation increased to 0.3 mil. Maximum values of a similar effect on the Aiming Circle M1 were found to be 0.04 mil. The extent of the effect, both on the Soviet Aiming Circle and the Aiming Circle M1, is small enough not to affect significantly the accuracy of the instrument.

The elevation mechanism permits elevation of the telescope of the Soviet Aiming Circle through a range of approximately 600 Russian mils — 300 in each direction from the horizontal. The micrometer knob, which rotates the elevation gear wheel through a worm drive, is divided into 100 divisions, each of which is equal to one Russian mil.



ORIENTATING MECHANISM LOCK

Figure 6. Soviet Aiming Circle
Azimuth Mechanism

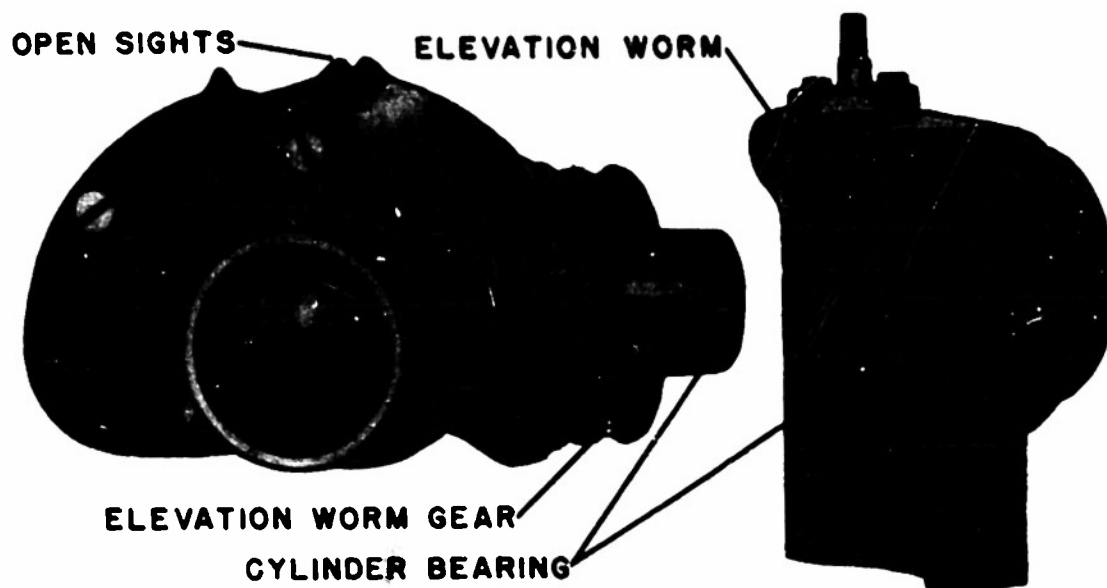


Figure 7. Soviet Aiming Circle
Elevation Mechanism

TABLE II
FLATNESS OF PLANE OF ROTATION

Az. Scale Setting (Russian Mils)	Variation from Flatness (mils) *	
	Initial	After Shock & Vibration
0	0	0
1000	+ 0.21	- 0.06
2000	+ 0.21	- 0.28
3000	+ 0.10	- 0.40
4000	- 0.15	- 0.30
5000	- 0.15	- 0.07
6000	0	0

* Positive values indicate inclination of line of sight from zero elevation. Negative values indicate depression of line of sight from zero elevation.

Graduations on the micrometer knob are marked for both inclination and declination of the telescope (see figure 2). The positive numerals for inclination are in red; the negative numerals for declination of the telescope are marked in black. The uniformity of the elevation scale graduations was found to be of the same order as that of the azimuth mechanism. Backlash in the elevation micrometer increased markedly from 0.1 mil before vibration and shock to 1.1 mil after vibration and shock treatment.

The accuracy of travel of the elevation mechanism was checked with a plumb line. Over an angle of 840 mils the travel departed from vertical by only 0.5 mil. After subjection to shock and vibration conditions the travel was found to depart from vertical by 1.1 mil over an elevation of the same magnitude.

The effect of play in the diopter setting on the accuracy of azimuth and elevation determination was investigated, and a comparison of the Soviet Aiming Circle and the Aiming Circle M1 was made in this respect. The magnitude of error introduced into the azimuth or elevation determination by play in the diopter scale was found - for both instruments - to be a maximum of several seconds. Thus, the effect of play in the diopter scale may be concluded to be negligible in the use of either the Soviet Aiming Circle or the Aiming Circle M1.

During the course of the shock and vibration tests, no externally observable effects on the Soviet Aiming Circle were noted. Azimuth and elevation settings did not change, and there were no resonance vibrations of the exterior components of the instrument. A summary of the mechanical features discussed in the preceding paragraphs is given in Table III.

2. Operation at Low and High Temperatures

To evaluate the mechanical operation of the Soviet Aiming Circle at low temperatures (-65° F), the torques required to operate the various mechanical components were measured at room temperature. They were then compared with values for similar quantities obtained at -65° F. These values are given in Table IV.

Although the low temperature torques were higher than the room temperature values in all cases, the increase in torques was not sufficient to cause difficulty of operation at low temperatures. The azimuth micrometer motion was choppy at room temperature, and even though the torque increased at -65° F, the operation was observed to be smoother at the lower temperature. At -65° F the azimuth worm and orientation worm throw-outs would not return to engagement when released. The azimuth and orientation movements (with worms disengaged) were found to be much stiffer at -65° F than at room temperature, but these movements were still readily accomplished.

The slip scale release required a force of 4-1/4 pounds to operate at -65° F, as opposed to 4 pounds at room temperature. The slip scale itself could be readily rotated at low temperature, but it was very difficult to do so with Arctic mitts. The diopter movement was very stiff and choppy at low temperature, but it too was usable.

Torque required to operate the azimuth micrometer, elevation micrometer, and orientation fine adjustment knobs at high temperature (+160° F) were of the same order as the room temperature values. These values are also given in Table IV. The mechanical operation of all components of the instrument was found to be smooth at +160° F and the ease of operation appeared greater in general than at room temperatures.

TABLE III
MECHANICAL ACCURACY

	Initial	After Shock & Vibration
Azimuth Micrometer		
Unit Graduation	1.07 mil *	
Variations of Scale from Uniformity	0.1 mil	
Backlash	0.2 mil	0.3 mil
Elevation Micrometer		
Unit Graduation	1.07 mil *	
Variations of Scale from Uniformity	0.1 mil	
Backlash	0.1 mil	1.1 mil
Maximum Variation from Flatness of Azimuthal Plane of Rotation	0.2 mil	0.4 mil
Variation from Plumb Travel of Elevation Mechanism (over 840 mil travel)	0.5 mil	1.1 mil
Change in Apparent Elevation with Opposite Rotation of Azimuth Micrometer	0.1 mil	0.3 mil

* 1 Russian Mil = 1.07 mil

TABLE IV
OPERATION AT LOW AND HIGH TEMPERATURES

Torque Required To Rotate Knobs (inch pounds)				
Motion	At Room Temp Initial	At -65° F	At +160° F	At Room Temp Final
Elevation Micrometer	1.4	1.6	1.3	1.4
Azimuth Micrometer	2.5	2.7	1.6	1.7
Orientation Fine Adjust- ment	2.0	2.0	1.8	1.8

Force Required To Operate Levers (pounds)			
		At Room Temp	At -65° F.
Azimuth Worm Throw-out	*Start	3.5	6.0
	*Release	4.0	7.0
Orientation Worm Throw-out	*Start	3.5	5.5
	*Release	4.0	6.0
Slip Scale Release		4.0	4.2

*Since the throw-out levers are spring loaded, the force required to depress the levers near the end of the stroke is greater than that at the beginning of the stroke. "Start" values indicate the force required to start the downward stroke of the lever; "Release" values give the force at the point where the worm becomes disengaged.

D. SENSITIVITY OF COMPASS

The sensitivity of the magnetic compass was determined outdoors to eliminate any effect due to the proximity of large masses of iron encountered indoors. With the compass needle set on magnetic north, the sight was centered on a distant line target. The instrument was then rotated off the target by means of the orientation fine adjustment knob and reset by aligning the compass needle and the corresponding index. The displacement of the line target was then measured with the azimuth micrometer. Backlash error was eliminated by approaching the target from both directions. The reproducibility of the setting of the compass, obtained by averaging a number of readings taken two different observers, was found to be 0.8 ± 0.3 mil initially. On repetition of these measurements after the completion of vibration, shock, and environmental tests, it was found that settings of the magnetic compass needle could be reproduced within 0.5 ± 0.3 mil.

The compass was observed to function properly at both low and high temperatures. The needle moved freely and the lock functioned properly under both conditions.

E. SENSITIVITY OF LEVELING DEVICE

While the Aiming Circle M1 utilizes both a tubular level and a circular level, the Soviet Aiming Circle has only a circular level (see figure 2). The level is graduated with three concentric etched circles. The angular displacement of the Soviet Aiming Circle required to shift the level bubbles with respect to these circular graduations was measured with an optical bevel protractor. An angular displacement of three minutes ($1 \text{ mil} = 3\text{-}3/8 \text{ minutes}$) was required to shift the edge of the bubble across the diameter of the innermost circle (see figure 8a). Similarly, it was found that the intermediate circle is 6 minutes and the outermost circle 9 minutes in diameter (see figure 8b and c). The level bubble itself is 4.4 mm in diameter (at room temperature) and is central within the limits of the intermediate circle of the vial with the instrument mounted in a truly vertical fixture.

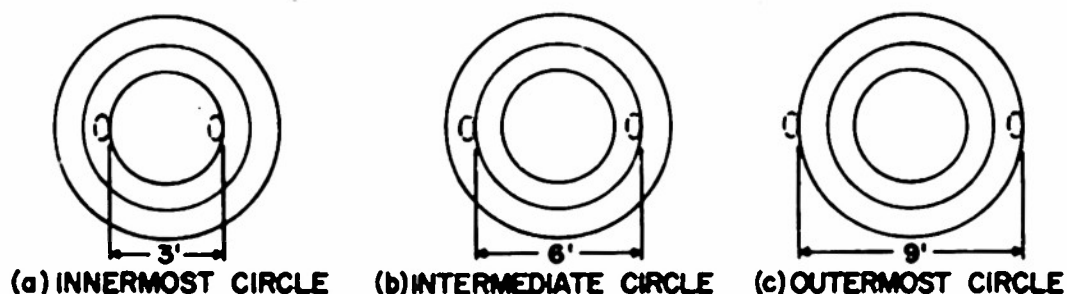


Figure 8. Bubble Level Measurements

F. ANALYSIS OF THE LUBRICANTS

Small samples of the lubricants from the Soviet Aiming Circle were analyzed by the Organic Chemistry Branch, Pitman-Dunn Laboratory. The following results were derived from a partial analysis only; complete analysis could not be made because of the small size of the samples.

Analysis was made on three separate items:

ITEM 1 - Grease on worms and gears

ITEM 2 - Sleeve material

ITEM 3 - Sealer

None of the items are common type metal soap grease. They appear to be petrolatum type material containing wax or oil thickened with some organic material. With the exception that graphite filler is one of the components of Item 1, no positive identification of the composition of these lubricants could be made.

Low temperature characteristics could not be determined because of the smallness of the samples. If the lubricants are petrolatum type materials, the low temperature characteristics are probably poor, since none of the materials of this type known in this country are good at low temperatures.

IV CONCLUSIONS

The Soviet Aiming Circle exhibits fine craftsmanship. However, the accuracy of the azimuth and elevation mechanism is essentially the same as that of the U.S. Army Aiming Circle M1.

Shock and vibration conditions normally expected to be encountered in its use are seen (Table III) to have little effect on the accuracy of the Soviet Aiming Circle, except in the case of the elevation mechanism, where considerable backlash and deviation from plumb travel developed.

The operation of the instrument at either high or low temperatures is not significantly different from its room temperature performance. The notable exception in this case is the failure of the throw-outs (for both azimuth and orientation settings) to return to worm engagement at low temperature. This failure is an indication either of poor low temperature characteristics of the lubricants or of inadequate strength in the respective springs at low temperature.

When the Soviet Aiming Circle was examined for desirable design features, it was found that the most notable of these have been known to American designers and, in some instances, have been put to use in our own instruments. Azimuth slip scales, for instance, are now in use on the Panoramic Telescope M1. Non-linear reticle scales similar to those found in the Soviet Aiming Circle are employed, as has been mentioned, in some American binoculars. However, American applications utilize these only as vertical range scales, while in the Soviet Aiming Circle, separate horizontal and vertical range scales are provided.

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V RECOMMENDATION

Although only a partial analysis of the lubricants could be made, the results indicate the need for a more thorough investigation of these materials. It is believed that the lubricants are composed either of petrolatum type material or of some material, unknown to us, which has been developed. In either case, complete identification of all components of these materials is necessary, not only in completing the evaluation of the Soviet Aiming Circle, but in the interests of keeping abreast of all technological advance. It is strongly recommended, therefore, that much larger samples of the lubricants be obtained, if possible, and that a thorough analysis of these materials be made.

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