EVALUATING THE KERN DKM2-A, SECOND ORDER THEODOLITE

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF CIVIL ENGINEERING
AND ENGINEERING MECHANICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN CIVIL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

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PREFACE

The interpretation of results and the conclusions stated in this thesis are solely those of the author, and do not necessarily represent the views of any other persons or departments.

I wish to express my thanks to Mr. Hans J. Wehrli, Executive Vice President of Kern Instruments, Incorporated in New York for providing me with the instrument under evaluation. Professor Philip B. Newlin of the Civil Engineering Department of the University of Arizona and Mr. William E. Carter of the Air Force Cambridge Research Laboratories have supplied helpful comments and criticism which have assisted me in the preparation of this thesis.

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ABSTRACT

The Kern & Company Limited of Aarau, Switzerland recently developed a liquid compensating mechanism which replaced the standard double image coincidence bubble. They combined this feature with the already proven design of Dr. Heinrich Wild into a new Second Order Theodolite which would hopefully provide the small engineer and surveying company with second order capabilities and possibly first order at a lower cost. Assessment of this instrument's capabilities were undertaken in as complete a manner as possible. The reading errors were found to be nominal, the graduation errors in the circles were found to vary at most by $\pm$ 1.5" which corresponds to a displacement of only 0.05 mm. The micrometer was found to deviate in run only by 0.012" plus a moderately flat scale variation curve. The instrument performed admirably in the field under adverse conditions though it did tend to be unreliable at colder temperatures, 50°F to 60°F, and down. The absolute measures as compiled by the instrument were not commensurate with its predicted capabilities. This variation is under investigation and will be hopefully remedied soon. The vertical circle collimation compensating mechanism did perform according to predicted values and beyond.

CHAPTER 1

INTRODUCTION

The quality of a theodolite is not determined by its size nor by the least reading of the micrometer. The best measure of excellence is the instrument's performance in actual field work. For an untried theodolite being used for the first time it is necessary to apply other tests.

A preliminary examination will show a great deal about workmanship and accuracy in the instrument. The five structural features which must be evaluated to form a rational estimate of accuracy of the instrument are: (1) graduation of the circles; (2) graduation and construction of the micrometer; (3) quality of the telescope's optics; (4) ease of operation with respect to tangent screws; and (5) the construction of the centers.

In the last 50 years precision engineering has undergone many advances. The most revolutionary change came in the development of glass circle theodolites of high precision. The traditional theodolites required circles having diameters of 228.6 mm to achieve a usually debatable least reading of 01.0". The optical theodolite has changed this by employing a circle of diameter equal to 75 mm and giving a precision to $\pm$ 0.5" or better.

The Kern DKM2-A is an instrument out of this era. It remains only to be tested, and proved in the field.

CHAPTER 2

DESCRIPTION OF THE INSTRUMENT

The DKM2-A Double Circle Theodolite is designed for triangulation, traversing, simple geodetic astronomy, precise industrial measurements, and optical tooling. The design is based primarily on principles introduced in the DKM3 by Dr. Heinrich Wild.

Telescope

The telescope can be plunged in both directions, its objective lens has an aperture of 45 mm, a minimum focussing distance of 1.7 m, a stadia multiplication constant of 100 and an addition constant equal to 0. The eyepiece provides a magnification of 30X.

Circle Reading

The instrument is a reiterating one; the horizontal circle can be displaced in either direction. The diameters are: vertical = 70 mm, horizontal = 75 mm.

Both circles are made of optical glass. Each circle consists of two concentric sets of sexagesimal graduations; the outer set consists of single lines and the inner set of double lines. The images of diametrically opposed portions of the circles are viewed in the micrometer eyepiece, one superimposed on the other. The optical micrometer moves each image optically with respect to one another. Settings for

readings are made by "symmetry" rather than "coincidence." The single graduation is placed symmetrically within the double graduation. Theoretically this system of reading ensures greater precision as the observer balances the micrometer setting in the same manner he balances the telescope collimation. It also gives directly the mean of two diametrically opposed circle readings in a single reading which is free of eccentricity. With the DKM2-A there is no need to count circle graduation lines. Setting the micrometer causes a bracket to automatically frame the appropriate ten-minutes interval number (the final zero is omitted for easier reading). The balance of the reading is taken from the micrometer scale which is used for either circle. The value of the angle to the nearest minute is taken from the large digits on the upper side of the micrometer scale. The remainder of the reading to the nearest second is taken from the smaller numbers on the lower side of the micrometer scale plus the count from the scale. This may be made to the nearest tenth of a second by estimation (see Figure 1).

The light required to read both circles is furnished by a single mirror which can be rotated and tilted. When electric illumination is desired, the mirror may be folded down and a lighting fixture plugged into the illumination opening.

The images of the circles and the micrometer scale are seen through a green filter which reduces eye fatigue.

Figure 1. Optical Micrometer

Levels and Compensator

The plate level, sensitivity of 20" per 2 mm, is set deeply into the alidade to protect it from external influences.

The vertical collimation level has been replaced with a new mechanism. It is based on the principle of total reflection of light rays from the surface of a liquid. This type of compensator is used because of its favorable damping properties and its simple and rugged construction. The range of inclination over which the compensator will operate is ± 01', the compensator precision is better than ± 0.3" and the compensator adjustment time is approximately 3 seconds.

A striding level will be provided at extra cost and has a sensitivity of approximately 6" per 2 mm.

Optical Plummet

The instrument has an optical plummet mounted in the alidade. If the plummet is not in proper adjustment the mean of two diametrically opposite positions locates the prolongation of the vertical axis. The elimination of an adjustment system means greater stability.

Physical Features

The instrument is painted a yellow green, weighs 6.8 kg and the vertical axis measures 17.1 cm.

CHAPTER 3

LABORATORY ANALYSIS

The examination of the quality of a theodolite is dependent on a knowledge and understanding of the instrument's innate characteristics. Knowledge of the values and locations for graduation errors intrinsic in the graduated circles and micrometer scales is paramount. Hence the first steps in this examination were aimed at studying the precision in reading the micrometer, micrometer scale graduations, circle graduations, and the vertical collimation system.

Reading Error

The reading error, that error intrinsic in every measurement attributable to the visual resolution limit of graduation coincidence, was examined in the following manner.

It was assumed that due to the symmetry involved in the physical construction of the DKM2-A that a mean error based on readings taken on only one circle would be representative. The horizontal circle was chosen primarily because of the ease and convenience of reading the micrometer over a wide range of actual circle graduations. It is clear from the design of the instrument that in order to read over the entire vertical circle would be largely impossible unless the instrument were equipted with diagonal eye pieces. Readings on different portions of the circle were angularly equidistant to eliminate graduation errors.

This program was implemented by taking four series of ten readings. The mean reading error and the maximum deviation from the mean for each series is tabulated below.

TABLE 1.

Reading Error

Series	Mean Error	Maximum Deviation
I	± 0.961"	+ 1.6" - 1.4"
II	± 0.777"	+ 1.0" - 1.8"
III	± 0.769"	+ 1.7" - 1.8"
IV	± 0.552"	+ 0.6" - 0.8"

The mean reading error of the horizontal circles was:

± 0.778"

Optical Micrometer

The optical micrometer was considered in two steps. Firstly the angular value of the overall graduation of the micrometer itself was verified and secondly the graduation error of various divisions of the micrometer scale was determined.

The value of the whole graduation or the micrometer run was effected in the following manner. The micrometer was set to zero; then, using the circle setting slow-motion screw, the horizontal circle graduations were set to coincidence; next, using the micrometer, a coincidence

was made on the adjacent graduation and a reading taken. The micrometer was read twice in each position and the mean used. The operation was applied in 18 positions of the circle spaced 10° apart to aid in elimination of horizontal circle graduation error. This error tends to be periodic.

The micrometer run was taken to be the mean of all observations and its mean error was computed from the means of the double readings, using the equation (*Examination of the Precision of Kern DKM3 Theodolites*, Military Geographic Institute, Florence, Italy, p. 10, [Fondelli, 1955]).

$$m = \pm\sqrt{\Sigma v^2/2n(n-1)} \ .$$

The angular value found was:

$$10' \ \ 00.012'' \pm 0.090'' \ .$$

The determination of the graduation error of the various divisions of the micrometer scale was accomplished by comparing the micrometer scale with the interval between the two lines of the graduations on the inner horizontal graduated circle. The diametrically opposed single graduation of the outer horizontal graduated circle was used as an index.

The scheme of observation was as follows: (1) with the micrometer set to zero, coincidence was made between the selected index and the left hand line of the double graduation using the circle setting

slow motion screw; (2) coincidence was then set exactly with the micrometer and the scale read; (3) coincidence of the index and the right hand line of the double graduation was made with the micrometer and the scale read; (4) the circle setting slow motion screw was then used to displace the left hand line back to the index without affecting the micrometer; (5) coincidence was made exactly with the micrometer and the scale read; (6) this procedure was repeated nine times to cover the run of the micrometer. Each setting of the micrometer was executed twice so that each reading is the mean of three settings. The complete sequence was then reversed working from right to left, starting from the 10' division.

It was assumed that the mean of all the values obtained was the most probable value of the interval between the two lines of the double graduation.

If ℓ_i and ℓ_{i+1} are the readings at the ends of an interval, ε_i and ε_{i+1} the relative graduation errors, and v_i, $+1$ the difference between the mean interval, α, and the difference in readings, $\ell_{i+1} - \ell_i$, then

$$(\ell_{i+1} - \varepsilon_{i+1}) - (\ell_i - \varepsilon_i) = \alpha$$

and

$$\ell_{i+1} - \ell_i = \alpha + v_i, \quad +1$$

The graduation errors of the micrometer divisions working from left to right (0' to 10') are then given by

$$\varepsilon_{i+1} = \varepsilon_i + v_i, \ +1$$

The graduation errors working from right to left (10' to 0') are given by

$$\varepsilon_{i+1} = \varepsilon_i - v_i, \ +1 \ .$$

The initial graduation, 0', was assumed to be correct. The error in the 10' graduation was taken as the excess determined from the micrometer run measurements. The resulting values for two complete such studies were meaned hence assuring a good representation. The graduation errors found are plotted in Figure 2. The two graphs (right to left), (left to right) were averaged yielding a curve which represents a plot of the most probable values of the graduation error of the micrometer scale.

Horizontal Circle Graduation Error

The method suggested by the United States Coast and Geodetic Survey (see pages 38 to 41, Special Publication No. 247, U. S. Dept. of Commerce, Coast and Geodetic Survey, *Manual of Geodetic Triangulation,* [Gossett, 1959]) was chosen for evaluation of the horizontal circle graduations.

Six prominent radio, television transmission towers equally spaced around the horizon were chosen. These towers are 1-1/2 miles or more from station C. E. (U. S. C. and G. S. 1st Order Triangulation).

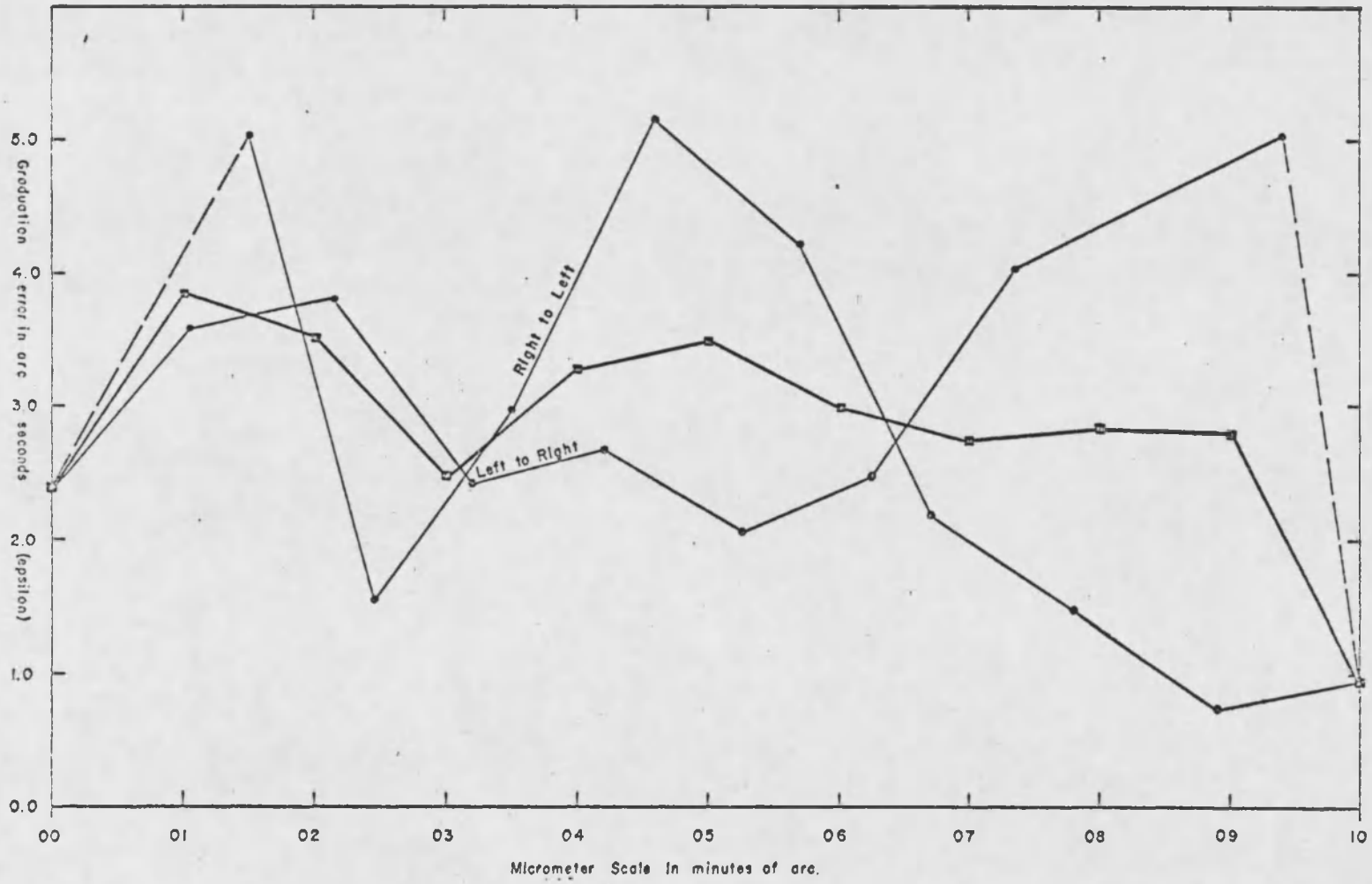

Figure 2. Graduation Error - Micrometer Scale

Table 2 is the abstract of directions resulting from occupation of station C. E. with the theodolite. Sixteen positions were taken with a rejection limit of ± 5.0" from the mean. This limit resulted in 9 rejected directions which were redetermined the same evening. All observations were made from about 7:30 P.M. to 9:00 P.M. Though the vertical angles to the towers were about 1° the instrument was leveled with the striding level (2mm equals 05.8").

The means of all directions were computed to the nearest tenth of a second. The residuals, the amounts necessary to correct each observation to the mean, are tabulated in Table 3. In column "A" these are zero, as Tower 1 was used as the initial. Column 6 is a list of the average residuals for each position, with the sign reversed. This average value was determined by adding up the six residuals algebraically, multiplying by - 1 and dividing by six. Note that this sum includes the residuals for all directions including the initial.

Table 4 contains the corrected residuals. These values were derived by applying algebraically for each position the values in Column 6 to those in the other columns. The numbers in parentheses indicate the portion of the horizontal circle, to the nearest degree, at which each residual was generated. In the general application of this method the portion of the circle studied is from 0 to 180 degrees because the residuals are the result of the combined portions of the circle 180 degrees apart. Due to the concentric circle design intrinsic to the DKM2-A the entire circle (0 to 360 degrees) was analyzed.

TABLE 2.

Abstract of Directions

Position No.	Tower 1 0° 00'	Tower 2 39° 13'	Tower 3 109° 58'	Tower 4 204° 42'	Tower 5 239° 47'	Tower 6 327° 59'
1	0.00	05.6	27.9	35.5	49.4	22.7
2	0.00	03.5	31.9	31.8	47.4	20.3
3	0.00	08.1	34.8	35.4	52.2	17.7
4	0.00	03.9	28.8	33.3	51.7	19.6
5	0.00	06.4	29.9	34.4	46.8	20.6
6	0.00	08.6	33.4	35.8	46.8	25.9
7	0.00	08.3	35.6	37.5	46.1	22.9
8	0.00	05.4	29.7	33.5	52.8	23.0
9	0.00	05.4	35.2	34.5	46.0	19.2
10	0.00	02.1	31.7	35.1	51.1	23.2
11	0.00	10.0	28.7	31.3	51.6	21.9
12	0.00	04.3	31.6	30.8	45.4	17.1
13	0.00	03.7	28.7	31.3	50.0	19.0
14	0.00	03.3	31.3	32.8	44.4	20.3
15	0.00	05.7	32.1	35.7	48.0	19.7
16	0.00	02.0	29.6	31.8	52.8	18.4
Sum		86.3	500.9	540.5	782.5	331.5
Average		05.39	31.31	33.78	48.91	20.72

TABLE 3.

Residuals

	A	B	C	D	E	F	G
Pos.	Tower 1	Tower 2	Tower 3	Tower 4	Tower 5	Tower 6	$-\frac{\text{Sum}}{6}$
1	0.0	-0.2	+3.4	-1.7	-0.5	-2.0	+0.2
2	0.0	+1.9	-0.6	+2.0	+1.5	+0.4	-0.9
3	0.0	-2.7	-3.5	-1.6	-3.3	+3.0	+1.4
4	0.0	+1.5	+2.5	+0.5	-2.8	+1.1	-0.5
5	0.0	-1.0	+1.4	-0.6	+2.1	+0.1	-0.3
6	0.0	-3.2	-2.1	-2.0	+2.1	-5.0	+1.7
7	0.0	-2.9	-4.3	-3.7	+2.8	-2.2	+1.7
8	0.0	0.0	+1.6	+0.3	-3.9	-2.3	+0.7
9	0.0	0.0	-3.9	-0.7	+2.9	+1.5	+0.0
10	0.0	+3.3	-0.4	-1.3	-2.2	-2.5	+0.5
11	0.0	-4.6	+2.6	+2.5	-2.7	-1.2	+0.6
12	0.0	+1.1	-0.3	+3.0	+3.5	+3.6	-1.8
13	0.0	+1.7	+2.6	+2.5	-1.1	+1.7	-1.2
14	0.0	+2.1	0.0	+1.0	+4.5	+0.4	-1.3
15	0.0	-0.3	-0.8	-1.9	+0.9	+1.0	+0.2
16	0.0	+3.4	+1.7	+2.0	-3.9	+2.3	-0.9

TABLE 4.

Corrected Residuals

Pos.	Tower 1	Tower 2	Tower 3	Tower 4	Tower 5	Tower 6
1	+0.2(000)	+0.0(039)	+3.6(109)	-1.5(204)	-0.3(239)	-1.8(327)
2	-0.9(011)	+1.0(050)	-1.5(120)	+1.1(215)	+0.6(250)	-0.5(338)
3	+1.4(022)	-1.3(061)	-2.1(131)	-0.2(226)	-1.9(261)	+4.4(349)
4	-0.5(033)	+1.0(072)	+2.0(142)	0.0(237)	-3.3(272)	+0.6(000)
5	-0.3(044)	-1.3(083)	+1.1(153)	-0.9(248)	+1.8(283)	-0.2(011)
6	+1.7(055)	-1.5(094)	-0.4(164)	-0.3(259)	+3.8(294)	-3.5(023)
7	+1.7(066)	-1.2(105)	-2.6(175)	-2.0(270)	+4.5(305)	-0.5(033)
8	+0.7(077)	+0.7(116)	+2.3(186)	+1.0(281)	-3.2(316)	-1.6(045)
9	0.0(088)	0.0(127)	-3.9(197)	-0.7(292)	+2.9(327)	+1.5(055)
10	+0.5(099)	+3.8(138)	+0.1(208)	-0.8(303)	-1.7(338)	-2.0(066)
11	+0.6(110)	-4.0(149)	+3.2(219)	+3.1(314)	-2.1(349)	-0.6(077)
12	-1.8(121)	00.7(160)	-2.1(230)	+1.2(325)	+1.7(000)	+1.8(088)
13	-1.2(132)	+0.5(171)	+1.4(241)	+1.3(336)	-2.3(011)	+0.5(099)
14	-1.3(143)	+0.8(182)	-1.3(252)	-0.3(347)	-3.2(022)	-0.9(110)
15	+0.2(154)	-0.1(193)	-0.6(263)	-1.7(358)	+1.1(033)	+1.2(121)
16	-0.9(165)	+2.5(204)	+0.8(274)	+1.1(009)	-4.8(044)	+1.4(132)

Figure 3 shows the plotting of the residuals at the corresponding portions of the circle. A series is plotted for each column and the points connected by straight lines. A series of mean values were then computed at intervals of 10° and a mean curve plotted. Figure 4 is the resulting mean curve.

Better results could have been obtained in a laboratory, employing collimators as sighting targets. The results obtained are a very good approximation to the true situation and it is felt that these graduation errors would be the ones most probably "seen" by the engineer or surveyor purchasing this instrument.

Vertical Collimation

The most significant feature of the DKM2-A is the vertical circle collimation mechanism. To study this mechanism a vertical angle test range was constructed in the patio area of the Civil Engineering Building, University of Arizona. All measurements were made at night with lighted targets.

The targets were marked on paper, and affixed to the north wall of the building with paper cement. Three such targets were set. Target A was 1.60 meters; Target B was 5.79 meters; and Target C was 10.15 meters above the patio floor. The instrument was set up 38.47 meters distant to the south from the line of targets. The instrument was carefully leveled with the plate level and then refined with the striding level. A wooden ruler was glued to an existing concrete wall some 3 to 4 meters distance from the instrument and once the instrument was

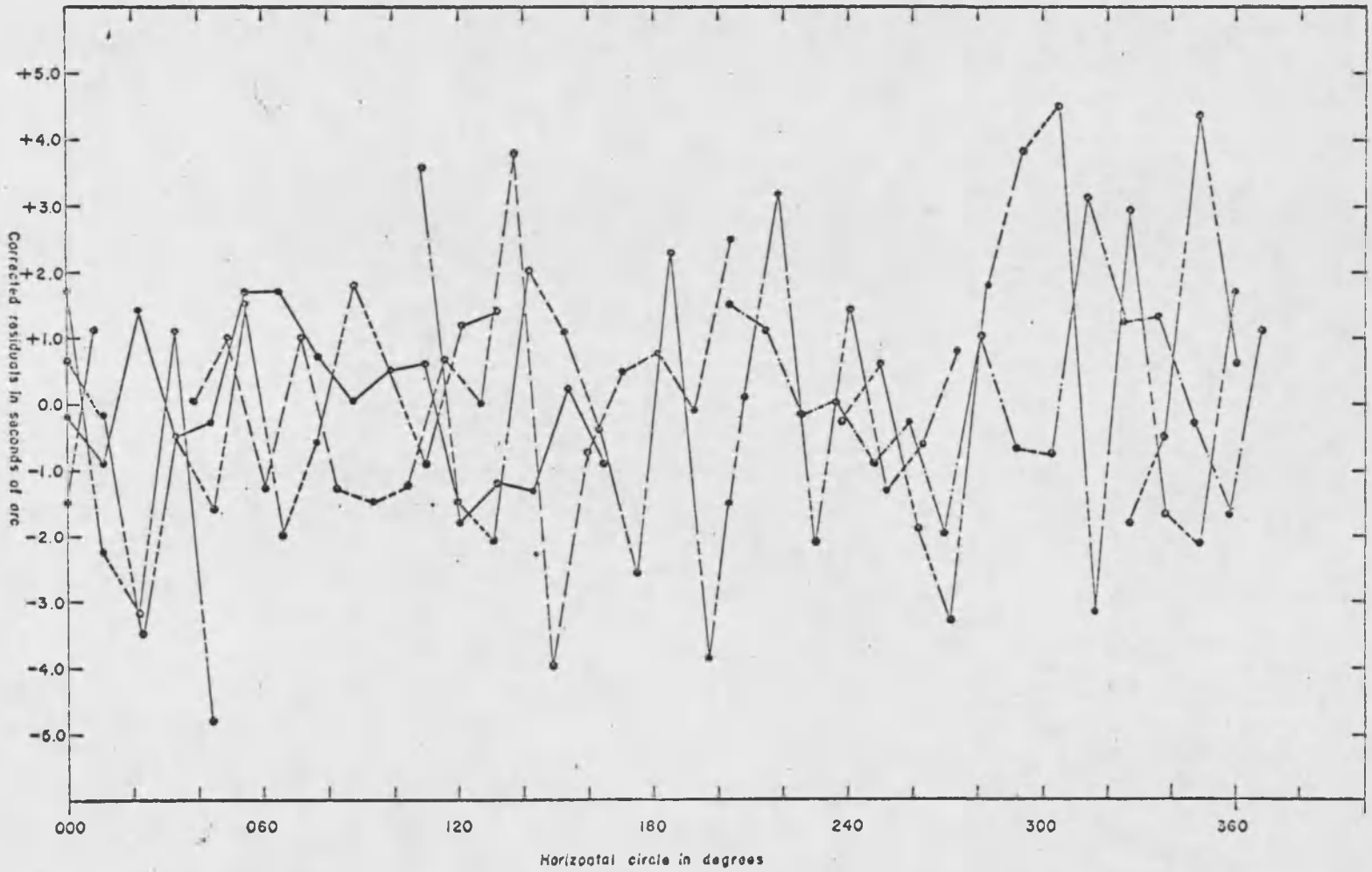

Figure 3. Horizontal Circle Corrected Residuals

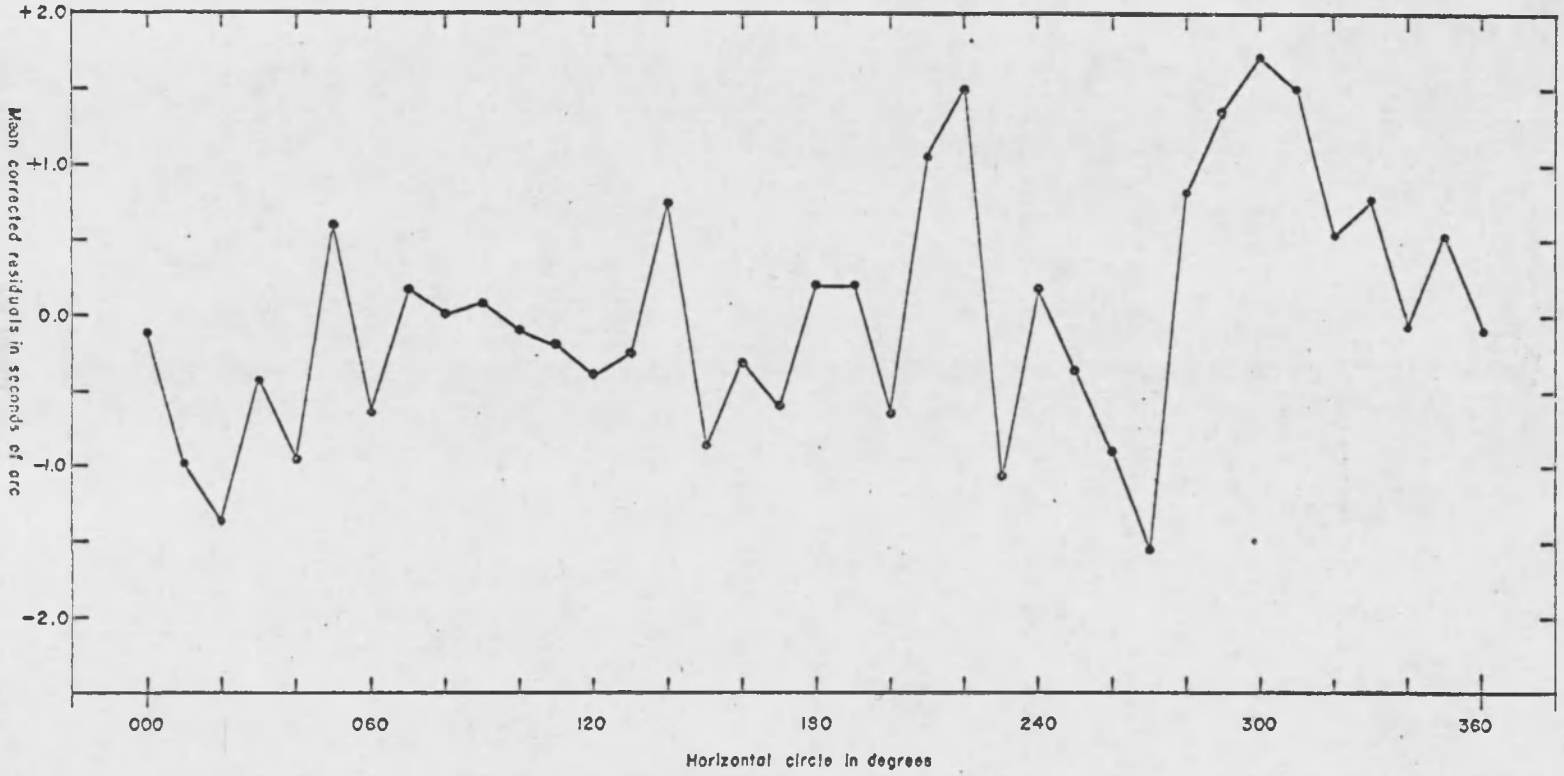

Figure 4. Horizontal Circle Graduation Error

readied the relative orientation was checked by sighting on the ruler with the vertical circle set to 90° 00' 00". By carefully bucking the instrument in, the relative height of the instrument was maintained to within ± 0.01 cm. The tripod feet fit firmly into holes drilled into the patio floor, and finally the instrument was constrained to being centered over a reference mark to within ± 0.1 cm.

The values of the angles were determined with an instrument whose reliability for precision and acceptability as a one second theodolite was beyond question. The DKM2-A was then used to measure these angles. The deviation between results is insignificant for angles A and B. The deviation for angle C appears large but is still within the standard deviation of the field results. The results follow in Table 5.

TABLE 5.

Vertical Angles

A	and	B
Record:	+ 0° 18' 10.1" ± 0.5"	+ 6° 31' 13.4" ± 0.3"
DKM2-A:	+ 0° 18' 10.0" ± 0.2"	+ 6° 31' 14.0" ± 0.9"

C	
Record:	+ 12° 49' 16.0" ± 0.7"
DKM2-A:	+ 12° 49' 14.6" ± 0.6"
Number of measures:	Record: 3, DKM2-A: 18

Once the instrument's capabilities had been proven a target was set and the angle measured under increasing angles of inclination. The inclination was carefully monitored with the instrument's striding level up to a value of 20". The tilting was extended to the limits of the plate vial or about 40".

The inclination angle of interest is the angle measured in the plane of the cross hairs when the instrument is on the target. No increase or decrease in circle index error or change in the value of the angle could be seen for the entire inclination range. It should be noted that at 35" of inclination the mechanism appeared to hang up and a variance of some 20" was seen in the direct reading. The cross hair was moved off of the target and placed on again, the reading taken and found to back at the accepted value. All measurements for this test were made inside of the Civil Engineering Department's surveying laboratory.

CHAPTER 4

FIELD ANALYSIS

Once the intrinsic properties and precision of the instrument were mapped the next logical step was to field test it. During the field testing careful attention was paid to the ease of setting and centering the instrument over the monuments, ease in handling, effect of wind and sun and the effect on the human element.

The work consisted of three operations this grade of instrument would probably be purchased for. These were: Azimuth determination by astronomical means, triangulation and trigonometric leveling.

Azimuth

Observation of Polaris for azimuth was chosen as an ideal field study of the DKM2-A. Strict adherence to first order techniques as outlined in Special Publication No. 237, *Manual of Geodetic Astronomy*, U. S. Department of Commerce, Coast and Geodetic Survey, [Albert J. Hoskinson and J. A. Duerksen, 1952], was maintained on the assumption that by being over cautious the true merits of the instrument would not be masked by other sources of error.

The observation program consisted of generating 34 separate observations over two nights observing time. Eighteen positions were observed the first night and sixteen exactly one week later.

Upon completion of all reductions a range of from 111° 05' 55.5" to 111° 06' 13.9" (based on South equal to 0° 00' 00.0") resulted. Taking the premise of first order the rejection limit of ± 5.0" was applied resulting in rejection of 10 of the 34 positions. The resulting probable error of the mean azimuth was found to be ± 0.40". The criterion for first order azimuth is ± 0.30". That for second order, Class I being also ± 0.30". The value determined did qualify as second order, Class II as the criterion is ± 0.50".

It is felt that several possible sources of error were at work here. Under the conditions of observation, that is cold enough to modify the efficiency of the lubricant used on the coarse horizontal circle setting dial, the instrumental error due to inclination tended to grow during each position. To be more explicit it appeared as though the torque generated by setting the circle to a new intial tended to compromise the "level" status of the instrument. In the beginning of the observation cycle the presence of circle drag appeared to be non existent but as the temperature dropped the readings began to indicate some form of either unsystematic dragging or hanging up of the circle. At any rate it is felt that these two factors aided in the compromise of azimuth accuracy.

Triangulation

For this study a long time established quadrilateral, located in a local aerial camera calibration range control net, was chosen.

Each direction was measured eight times, as suggested for second order work. The probable errors computed for each direction varied from ± 0.66" to ± 0.27". There were only two rejected directions in the entire program. The geometric angular closures were not at all commensurate with these values. The error of closure for the quadrilateral was + 18.07", that for each of the four included triangles were + 19.48", - 19.88" + 27.95" and - 1.41". These results raised many questions as to possible sources of error. All targets were centered and plumb as was the instrument hence ruling out any large eccentricity. All observations were made during the late afternoon. The instrument was not shaded as this test was to resemble the field conditions imposed by the consumer. It should be noted that the sky was overcast about 60% of the observing time.

Due to these dismal results the DKM2-A was used to measure other angles in the control net and was found to vary a consistent + 5" to + 6" from the accepted values.

A careful study once again indicated an apparent unsystematic dragging in the horizontal motion. It is not evident at this time as to what the cause of this variation is, but the instrument will be returned to Kern in hopes that this is just the malady of a particular instrument.

The triangle whose error was only - 1.41" was adjusted and all distances computed. The agreement with record was on the order of one part in 40,000. This value is quite respectable.

It should be noted that the angles which were compared with record consistently varied as much as 10" on the average, with reasonable closures being observed only in the above adjusted triangle.

Trigonometric Leveling

In conjunction with the triangulation test the DKM2-A was employed to measure the vertical angles to each station for the reason of determining their elevations by trigonometry.

Trigonometric leveling has taken on a new face with the ever increasing demand for high density lower order elevations in photogrammetric control systems. The DKM2-A is particularly well suited to this application as are all second order theodolites. The author has witnessed results qualifying for high third order accuracy generated trigonometrically and being checked closely by higher order data. The method does require good ground conditions and optimum station locations, however, before such work is possible. The conditions do exist on the camera calibration range and in particular on the test quadrilateral previously studied.

Reciprocal vertical angles were observed, contributing to the highest possible accuracy. The previously discussed triangle was used and the loop closure calculated. The error was + 0.04". The third order criterion for a loop of this length (6,000 feet plus) is ± 0.06'.

CHAPTER 5

CONCLUSIONS

The DKM2-A proved to be very stable under adverse wind conditions. It operated rather sluggishly at temperatures below 60°F though this is probably due to the lubricants used. The instrument is a very comfortable one to use from the standpoint of reading microscope organization and eye pleasing yellow-green light. The two speed tangent screws are certainly assets. The locks and tangent screws were located in a symmetric fashion though a good observer soon develops a sixth sense about his instrument and their location ceases to be of great importance. Possibly because of the lubricant again but no appreciable out of balance could be noted in the telescope. The small finder collimator proved to be very usefuly especially at night.

Features of the DKM2-A which were not favorable were few in number. The most significant being the coarse circle set. It is felt that the present location is not the best nor is its design commensurate with predicted applications. The fact exists at least for the particular DKM2-A under evaluation that under adverse weather conditions the setting of new initial directions tended to generate a level destroying torque. This change was observable through monitoring the inclination of the striding level axis. It is felt that by

relocating this motion so that the fine motion and coarse motion sets would operate co-axially to be to the best advantage. The proposition of having two such motions is definitely a step toward better acceptance of the instrument. Another feature needing modification was the mirror used to illuminate the cross hairs. It was too sensitive to position and the slightest brush of the hand set the telescope into darkness.

If the previously referred to malady of high relative precision but poor absolute accuracy can be overcome the DKM2-A will find much use as a second order theodolite. It was found that best results were obtained if the micrometer was read to the nearest ± 0.5". This is due to the large reading error intrinsic with graduations so closely spaced on the micrometer scale.

APPENDIX I

PHOTOGRAPHIC DISCUSSION OF THE DKM2-A

DKM2-A Canister and Pyramid Carrying Case.

DKM2-A, Tripod.

Back view, DKM2-A - (a) striding level, 5.8" per 2mm graduation, (b) horizontal axis clamp, (c) electrical light source, (d) horizontal axis tangent screw, (e) optical plummet, (f) leveling cam control knob, (g) power input, (h) vertical axis clamp.

Side view, DKM2-A - (a) vertical axis tangent screw, (b) battery pack.

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