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# Determining an azimuth with a gyrotheodolite

Kevin P. Logan

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This report is intended as a practical guide to surveyors for making measurements to determine an azimuth using a gyrotheodolite. This report gives a bried description of how the gyro works, improved observing procedures for its use, and the results of field observations. Accuracies of ± 5 arc seconds can be obtained.

# PREFACE

The effort covered by this report was conducted under the Civil Works Surveying and Mapping R&D Program, Work Unit 361-31748, "Use of Modern Technology for Survey."

This work was performed under the supervision of Mr. Peter J. Cervarich II, Chief, Precise Survey Branch; Mr. John G. Armistead, Chief, Surveying Division; and Mr. Eugene P. Griffin, Director, Topographic Developments Laboratory.

The author also would like to acknowledge initial efforts by Mr. Kenneth D. Robertson who started this project and worked on it until his retirement. His input and guidance were deeply appreciated and will be missed on future projects.

The author would also like to acknowledge the efforts of Mr. Jimmy Reeves, Chief, Survey Branch, Mobile District, Corps of Engineers, and his personnel for their cooperation in using the gyro in their normal field activities and for supplying data for evaluation.

Colonel Alan L. Laubscher, CE, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the Engineer Topographic Laboratories during the report preparation.

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## INTRODUCTION

Surveyors frequently require an independent means of determining an azimuth. Traditional methods that use the magnetic compass or stellar observations are either inaccurate or limited by weather and visibility conditions. A seemingly viable alternative is to use a gyrotheodolite. This instrument is accurate, does not require stellar observations and provides an efficient and effective means for obtaining geodetic north (in the northern hemisphere) in situations where other techniques cannot be used.

**History.** The instrument known today as the gyroscope was invented some time before 1813 and at that time was known as the precession machine. This device was used to demonstrate the precession of the earth while it rotated on its axis and revolved in its orbit around the sun. It wasn't until 1852 that the word "gyroscope" was proposed for this device. During the next 50 years, several different types of gyrocompasses were designed and tested. In 1909, Elmer A. Sperry patented a gyrocompass in the United States. Shortly after Sperry's patent, gyrocompasses were being considered as a means for finding direction in mines and tunnels. A paper presented to the Institure of Mine Surveyors in 1919 described a gyrocompass that could be used for this purpose. Instruments were designed and constructed in 1924 and 1936 for use in mine surveying. However, both of these instruments turned out to be too bulky for mine work. In 1948, an instrument called the Meridian Indicator was built in West Germany. The Meridian Indicator consisted of the outer globe of the gyroscope being rigidly attached to the base of a Fennel theodolite and mounted on a tripod. This instrument was taken to South Africa where it was used in gold mines for the next 10 years. The accuracy of the Meridian Indicator was about 1 minute of arc and had a precessional swing of 22 minutes of time. In 1961, a Fennel gyrotheodolite was produced that weighed approximately 50 kg. A few years later, two smaller instruments were produced. One was produced by Fennel and the other by Wild Heerbrugg in Switzerland. Wild Heerbrugg introduced the gyrotheodolite known today as the "GAK1".[1]

**Principles of the Suspended Gyrocompass.** The gyro is a wheel, rapidly spinning about an axle and mounted in a gimbal. An illustration of a suspended gryo is given in figure 1. One of the most noticeable characteristics of the gyro is its resistance to a change in the direction of its spin axis. When a heavy, rapidly rotating wheel is constrained so that its spin axis remains horizontal and precession can occur only around a vertical axis, then a torque due to the earth's rotation will cause the spin axis of the wheel to turn (precess) toward true north.[2]

Now imagine a gyro gimbal that is suspended by a thin tape above the earth's equator. Within the gimbal is a rotor capable of being spun at high speeds. Initially, the gimbal is aligned so that the spin axis of the rotor

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[1] G.B. Lauf, "Gyroscopic Surveying," Quarterly of the Colorado School of Mines, April 1970, Volume 65, No. 2

[2] R.C.H. Smith, The Suspended Gyrotheodolite, May 1980.
Publisher Unknown.

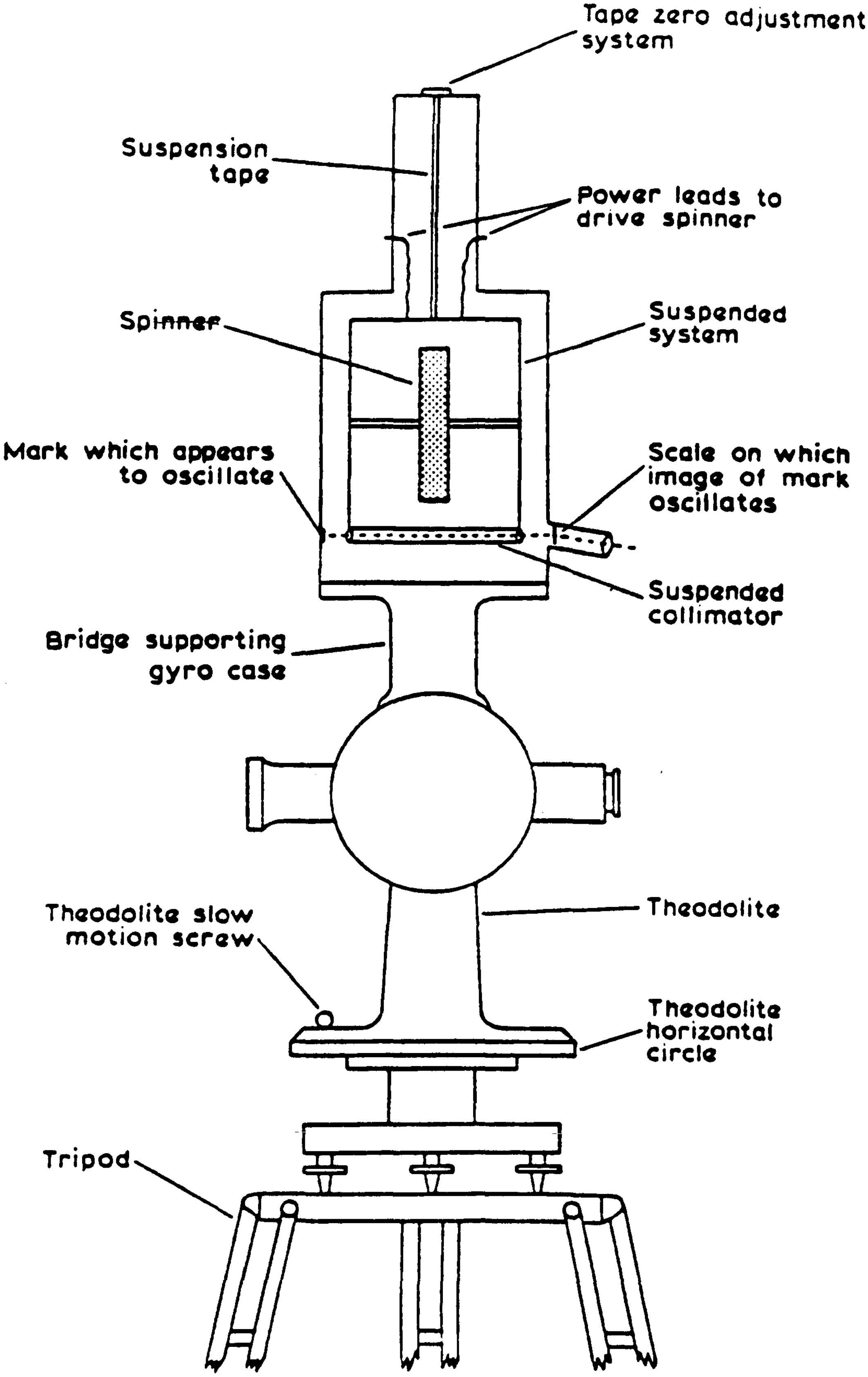

Figure 1. Suspended gyro.

is pointing in an east-west direction. Now, the rotor is spun so that the system becomes a gyroscope. Then, as the earth rotates, the rotor axis will, in effect, be tilted downward with respect to outer space. The gyroscope reacts to the motion by rotating (precessing) about the axis of the suspending tape.

The rest position for this configuration occurs when the gyroscope is aligned with its axis of spin in a meridian plane. In this orientation the gyro will be translated by the earth's rotation but will not experience an angular change i.e., the spin axis will not be tilted by the earth's rotation. If the gyro is suspended above one of the earth's poles, the spin axis will always be aligned with one of the meridians, and no tilt of the spin axis can occur. Consequently, the gyro is at a rest position. At a point between the pole and equator, the gyro will seek to point north, with the precessing force a function of the latitude.

If the gyro is pointed in a nearly north direction, it will swing (precess) towards north. As it passes north, the force will change direction. However, by this time rotational inertia about the suspension tape axis will force the gyro to swing past the rest point. Thus, the gyro will swing back and forth in simple harmonic motion with both the torsion in the suspension tape and the precession force causing the swings. At a point near the center of the motion lies true north. Using an optical lever technique similar to that of an old fashioned galvanometer, measurements are made of the amplitude of swings on either side of the zero mark of the reticle scale, and the time is noted when the gyro mark (crosshair) swings past the zero mark. A brief set of calculations will yield a correction to the theodolite plate reading to obtain the direction of true north.

**The WILD GAK1.** The WILD GAK1 gyro attachment is a small gyro that may be fitted to a T2 or T16 theodolite to locate the direction of true (astronomic) north or south when the equipment is used in the respective hemispheres (See fig. 2). Although this attachment has been available for over 10 years, it has found limited use, possibly because of the high price and an accuracy that has been limited to about 30 arc seconds. The price of the instrument is still high, but the addition of a vernier modification developed by the United Kingdom Royal School of Mines has increased the accuracy to approximately ± 5 arc seconds. The usefulness of the instrument at that level of accuracy makes it worth the price.

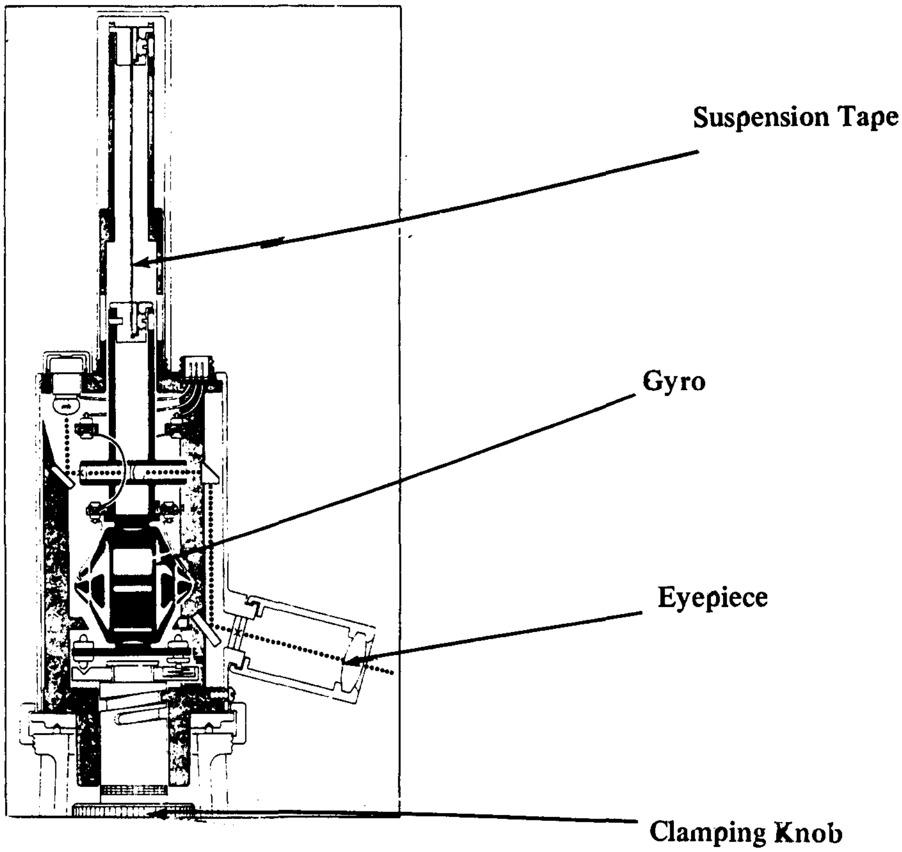

Figure 2. Cross-section of GAK1 gyro.

**Errors.** As is true with any survey instrument, best results are obtained when the sources of error are understood and reduced to a minimum. In the GAK1, there are four major sources of error.

The first error source is the proportionality constant of the tape suspension. The torque provided by the suspension is a function of the cross section of the tape as well as other factors. Although a method of calibration is given by WILD, an unacceptable residual error remains. Techniques for reducing this error were discovered in the course of field tests and were incorporated into procedures for instrument use. Details of these procedures are presented in the Appendix.

The second and third sources of error lie in the measurement of the amplitude of the gyro swings about north, and the measurement of the times at which the crosshair swings past the zero mark of the measuring reticle. The amplitude errors have been reduced through the vernier modification developed by the Royal School of Mines. This modification is an optical vernier similar to a parallel plate attachment to the automatic level. The timing errors can be reduced through multiple readings of the zero crossing.

The final error lies in the fact that the spin axis of the gyro and the optical axis of the theodolite are not in perfect alignment because of the mechanical coupling of the gyro to the theodolite. This means that the gyro must be set on a line of known azimuth and the difference between gyro north and optical north determined. This difference will remain constant unless the theodolite encounters rough handling. If rough handling occurs, the gyro should be reset on a line of known azimuth and rechecked. The difference should also be re-determined any time a suspension tape is changed.

**Testing.** Tests of repeatability were performed on an outdoor line in northern Virginia. A target was set up and carefully plumbed over a mark at a distance of approximately 200 meters from the instrument. Frequent measurements were made of the azimuth to the mark over a period of about 2 months. Experience obtained during these initial measurements resulted in improvements to the measuring procedures which yielded increased accuracy.

These operating procedures were further tested in cooperation with the U.S. Army Corps of Engineers Mobile District. The instrument was taken to an area near Dalton, Georgia, and Mobile District field survey personnel were trained in the use of the instrument and in data reduction techniques. The district survey team then made measurements of a large number of azimuths under a variety of operating conditions over the next 2 months.

**Discussion.** A certain amount of skill must be developed in order to obtain best results when using the instrument. The first day at Dalton was spent teaching district personnel the operating procedures of the instrument and how to perform the field data reduction. The second day, the crew began taking measurements and determined the azimuth of two different lines. On the third day, the same two lines were used to determine the repeatability of the gyro and two additional lines were measured for the first time. A two-person crew can determine at least four azimuths per day.

The next 2 months were spent taking repeated measurements of known lines to test for accuracy and repeatability. Azimuths were computed from the coordinates of the end points on these lines which were established either by Global Positioning System (GPS) or were published by National Geodetic Survey (NGS). After determining several azimuths on known lines and gaining confidence in the instrument and in themselves, the survey crew began taking measurements on lines whose azimuths were not known. Results comparing the known azimuths and the GAK1 azimuths can be found in Table 1.

**TABLE 1. AZIMUTH COMPARISONS**

| LINE | GAK1 AZIMUTH | NGS PUBLISHED AZIMUTH | DIFFERENCE (SECS) |
|---|---|---|---|
| 1 | 233-53-53 | 233-53-48 | 5 |
| 2 | 57-21-49 | 57-21-35 | 14 |
| 2 | 57-21-39 | 57-21-35 | 4 |
| 3 | 145-42-55 | 145-42-55 | 0 |
| 3 | 145-42-53 | 145-42-55 | 2 |
| 4 | 294-38-04 | 294-38-02 | 2 |
| 5 | 248-04-16 | 248-04-19 | 3 |
| 6 | 293-57-55 | 293-57-44 | 11 |
| 7 | 281-18-45 | 281-18-43 | 2 |

Because the initial set of observations on line 2 had such a large difference (14 arc seconds), a second set was taken approximately one month later. The cause of the large difference could not be determined. Likewise, the cause of the large azimuth difference on line 6 could not be determined. In this instance, the fact that the published coordinates for one end of line 6 were obtained by conventional survey methods while the coordinates for the other end of the line were determined with GPS could be a possible explanation. As a matter of interest, the published azimuths for lines 4 and 5 were computed only from coordinates established with GPS.

The average of all the differences in Table 1 is 4.8 arc seconds. Omitting the two observations with large differences results in an average difference of 2.6 arc seconds. These results are in agreement with the 5.0 arc seconds accuracy reported by the United Kingdom Royal School of Mines.

**Applications.** Because of its accuracy, it is believed that the GAK1 can be useful in at least three applications within the Corps of Engineers.

First, it can be used for the routine measurement of an azimuth where either sun or polaris observations are presently made. Because the gyro does not depend on any external observations, the weather or time of day are not as important as when making sun or polaris observations. (High winds would probably require an observing tent.).

Second, the gyro might be used for quality control. As more and more Corps surveys are performed under contract, it becomes increasingly important to develop techniques for checking the contractor's work. The GAK1 may be used anywhere in a traverse to determine an azimuth, which can then be compared with results supplied by a contractor.

Third, use of the Global Positioning System (GPS) is increasing because of its high accuracy and general usefulness. A single measurement with GPS produces first-order or second-order coordinates for a selected point relative to a known station, but does not produce an azimuth unless a third, intervisible, point is also measured. The gyro may be used to establish an azimuth while the GPS measurement of coordinates is being made. This might be done by setting up on the azimuth mark and measuring the azimuth back to the GPS antenna.

## CONCLUSIONS

Many experimental observations have been made with the WILD GAK1 to determine operating procedures that would give the best answers possible. During the course of these tests, techniques were refined to produce the highest accuracy commensurate with practical field usage. These experiments have been confirmed by a survey party from the Mobile District along with actual field measurements made by ETL personnel. From the results of these experiments and field tests, it is believed that by carefully following the procedures provided in this report, the GAK1 is capable of accuracies on the order of ±5 arc seconds.

This accuracy, plus the autonomous operating capability of the GAK1, make it a useful tool for many survey applications such as:

1. Replacing sun or star observations, especially in conditions of poor visibility.

2. Providing quality control of survey networks.

3. Providing azimuths for surveys established with the Global Positioning System (GPS).

# APPENDIX

## TECHNIQUES FOR USE WITH THE WILD GAK1 NORTH-SEEKING GYRO ATTACHMENT

A set of observations with the GAK1 may be made in about 1 hour and, when taken with care, is capable of providing results with an accuracy of ±5 seconds of arc. For a good instrument operator with theodolite experience, one or two day's training and a week's practice will be sufficient to produce a good gyro operator, as the same skills and care apply to the operation of either instrument.

*** CAUTION ***

The gyro must be in the clamped (caged) position **except** when final readings are being taken. The operator should read these instructions and the WILD operating manual before attempting to use the gyro.

*** CAUTION ***

## OPERATING PROCEDURES

The following operating procedures are simple extensions of the techniques described in the WILD operating manual for the GAK1 gyro. It is assumed that the reader is familiar with start up and basic operation of the instrument.

Set Up: With the aid of a compass or some other means, place the tripod over the mark so that one leg is pointing in the direction of north. This will later permit small adjustments of leveling in the east-west direction. Make certain that the tripod is firmly set in the ground. All precautions should be taken to insure absolute stability of the tripod during the approximately 1 hour duration of the measurements. The use of an umbrella is advised, even on hazy days.

Place the theodolite on the tripod, plumb, and adjust for a coarse level. Now mount the gyro to the bridge of the theodolite.

*** CAUTION ***

DO NOT OVER TIGHTEN THE ALUMINUM MOUNTING RING, AS IT MAY DISTORT AND CHANGE THE CALIBRATION CONSTANT OF THE INSTRUMENT.

*** CAUTION ***

Set the battery on the right side of the tripod leg that is pointing north, as this is the most convenient battery location while observations are being made. Remove the electrical cord and eyepiece from the battery case and connect to the gyro in their respective places. Next, level the theodolite as carefully as possible. Because of the the stiffness of the electrical cord it will help to clamp it onto the tripod leg in a position to provide slack at the gyro end. Let the instrument sit for a few minutes and then check the bubble to see if it has remained stable.

Leveling is very critical in obtaining the best accuracy. For every 2 seconds mislevelment, there will be a 1 second error in finding true north with the gyro. It is recommended that a theodolite with an automatic index be used with the GAK1. Final leveling should be made using the automatic index. Instructions for using the automatic index can be found in the WILD manual for the specific theodolite that is being used.

Starting the Gyro:

***** CAUTION *****

AGAIN, BE CERTAIN THAT THE GYRO IS IN THE CLAMPED (CAGED) POSITION BEFORE THE GYRO MOTOR IS TURNED ON.

***** CAUTION *****

Follow exactly the instructions in the WILD GAK1 instruction book for turning the gyro on and running it up to speed.

**Rough Orientation.** The gyro is only effective for determining north accurately when it is already pointed within about 15 minutes of arc of that direction. However, a simple preliminary measurement with the instrument will align the gyro within this tolerance. Set the horizontal tangent screw at the center of its run. Release (uncage) the gyro. This is done by bringing the clamping knob slowly down to the red line. Let the gyro settle for approximately 15 seconds, then continue to bring the clamping knob all the way down so that the gyro is fully uncaged. Release the horizontal clamp on the theodolite. The gyro crosshair will begin to move as the gyro seeks north. Turn the alidade by hand to keep the crosshair approximately centered within the scale.

***** CAUTION *****

DO NOT LET THE GYRO CROSSHAIR GO OFF SCALE. THIS WILL RESULT IN DAMAGE TO THE GYRO.

***** CAUTION *****

As the gyro passes north it will begin to slow down and will finally stop and reverse direction. As it approaches the reversal point, tighten the horizontal clamp and use the fine adjustment knob to put the gyro crosshair exactly on zero at the moment of reversal. Now read and record the horizontal plate reading. Again release the horizontal clamp and follow the crosshair in the other direction. Repeat the above steps as the gyro swings past north in the other direction and finally comes to the opposite reversal point. Again read and record the horizontal plate reading. CLAMP (CAGE) THE GYRO by turning the clamping knob gently back up to the red line, letting the gyro settle for approximately 15 seconds and then gently finish turning up the clamping knob until the gyro is fully caged. Determine the mean of the two horizontal plate readings. This value is the approximate direction of north.

Example:

| | |
|---|---|
| Horizontal Plate Reading #1= | 18-01-41 |
| Horizontal Plate Reading #2= | 46-15-25 |
| Mean Plate Reading = | 32-08-33 |

Reset the horizontal plate angle to the mean angle that was obtained from performing the rough orientation. This is the angle that the first correction will either be added to or subtracted from to get true north.

**Final Readings.** There are two methods of making the final readings to determine true north. One is the reversal method and the other, the transit method. The transit method will be used in these procedures. These procedures will also be used in making some initial calibrations.

Before beginning the final measurements, check the leveling of the theodolite and make any needed adjustments. Once measurements have begun, the alidade will be clamped in position and cannot be moved.

If the gyro has been modified with an optical vernier (added above the telescope) set the vernier zero to the mark on the gyro. The vernier is similar to the parallel plate attachment on a level and permits reading the amplitude of the gyro swings to 0.01 scale divisions. Estimate the amplitudes if the gyro does not have a vernier.

Again, bring the clamping knob slowly down to the red line and let it settle for 15 seconds. After it has settled, finish bringing the knob down until the gyro is fully uncaged. Bring the knob down slowly so it doesn't induce any extra torque into the swing. This will help in keeping the swing on scale. The gyro will start to move to one side. It should start slowly. If it doesn't, use the gyro knob to dampen the oscillation to keep the swing on scale. Try to get the amplitudes to fall between 10 and 14 scale divisions. This will give adequate swing times. Watch the swings to both sides to make sure they stay on scale and reach amplitudes of 10 to 14 scale divisions. If they don't, cage the gyro and try again. When the amplitudes are satisfactory, start recording swing times.

The main objective in getting good swing times is to be consistent with stopping the stopwatch as the gyro crosshair passes the zero mark on the scale. This comes with practice. The swing time is the time it takes for the gyro to swing from the zero mark on the scale out to its maximum amplitude (reversal point) and back to zero. A stopwatch is required that will permit lap times to be measured. Start the stopwatch. As the crosshair crosses zero on the scale, press the lap time plunger on the watch and record the time to the nearest 0.1 second, and the direction of the swing as the crosshair passes zero. The direction of the swing determines whether the correction will be added to or subtracted from the horizontal plate reading. Don't forget to press the watch plunger again to allow the stopwatch to continue counting the accumulated time. Continue this process until seven zero crossing times have been recorded.

At least two good amplitude readings are needed for calculations. These are taken during swing time measurements. The amplitudes are read and recorded when the gyro reaches its maximum swing or reversal point and starts back in the opposite direction. The first amplitude reading on each side should be estimated. This will help in making the final two amplitude readings, using the vernier modification. If the gyro doesn't have the vernier modification, four estimated amplitudes should be taken and the statistical mean used for the calculations. The vernier is adjusted to keep the crosshair on one of the whole division marks at the time the swing reaches its reversal point. The vernier reading is then added to or subtracted from the value of the whole division mark, depending on which side of the scale it's on.

**Example.** Suppose the estimate of amplitude was 11.3 divisions on the right side of the scale. After the crosshair has crossed the zero mark and is swinging to the right side of the scale, the vernier is set on 70. The reason for this is that the vernier reading is subtracted on the right side of the scale from the whole division mark that the crosshair stops and reverses direction on. The crosshair should come to a complete stop fairly close to the 12 division mark. The vernier will have to be adjusted at this time to keep the crosshair exactly on the 12 at the time it reverses direction. The vernier then might read 66 divisions. The total amplitude on the right side would then be 12.00 - 0.66 = 11.34 divisions. The total range of the vernier is only slightly more than one of the scale divisions seen in the gyro telescope. This is the reason for estimating the first amplitude reading on each side. Unfortunately, readings of the vernier are subtracted on the right side, as shown above, and added on the left side. For example, in the case above the vernier should be used to hold the crosshair on 11 on the left side and the vernier reading would then be added. Experiment with the vernier when the gyro is caged to see the effect of vernier movement.

***** CAUTION *****

REMEMBER TO SET THE VERNIER BACK TO ZERO AFTER AN AMPLITUDE READING. THE VERNIER MUST BE AT ZERO WHEN THE TIME OF ZERO CROSSING IS READ WITH THE STOPWATCH.

***** CAUTION *****

When seven zero crossing times and two good amplitudes have been read, the first series of measurements is complete. Reduce the data as shown in the Data Reduction section and calculate the correction to the theodolite plate reading. If this correction is greater than 30 seconds of arc (the usual case), a second series of measurements is required. The second set of readings is taken with the same procedure as the first, except that the initial horizontal plate reading should be corrected to read the value calculated from the first set of readings. The final correction should be less than 30 seconds of arc. If the final correction should be greater than 30 arc seconds, repeat this sequence until it is less than 30 arc seconds.

# INITIAL CALIBRATION

There are three requirements that need to be attended to before the instrument may be used in the field. One of these is an adjustment, and the other two are calibrations.

The first requirement is to adjust the tape zero. If the gyro is not spinning, the position of the crosshair should lie at the zero mark on the scale. With the gyro mounted to the theodolite, connect the battery and level the instrument. Turn the battery starter switch to RUN for just a second and then back to OFF. Unclamp (uncage) the gyro and, if necessary, use the clamp to dampen the gyro oscillations so that the crosshair remains on scale. The gyro should oscillate with a half swing of about 30 seconds. Record the amplitude of the oscillations on both sides of the mark. The mean of the two values is the rest position of the crosshair. This value should lie within one scale division of zero. If it does not, follow the directions for adjustment of the tape in the WILD manual.

The second requirement is to determine the gyro proportionality factor. When making a measurement, if the instrument is not pointing directly north, the restoring force of the spinning gyro and the torque of the tape will work together for one part of the gyro swing, and against each other for another part of the gyro swing. This will result in a greater swing amplitude on one side of the zero scale mark than on the other. To determine the relative magnitude of the forces exerted by the gyro and the tape, a determination must be made of the proportionality constant "c" for each GAK1. This constant is determined by making two sets of measurements of north using the procedures stated below. One north pointing is made approximately 15 minutes to one side of north and the second pointing approximately 15 minutes to the other side of north. The results of both measurements will be utilized to calculate the proportionality constant "c".

**Example.** The first pointing for determing the proportionality constant was to the west side of north (table 2). The second pointing was exactly 30 minutes east of the first (table 3). Five transit times and four amplitudes were taken at each setting. The following are the actual numbers obtained during these readings.

Original Plate Reading #1 = $N_1'$ = 118-58-20

### TABLE 2. OBSERVATION FIELD NOTES, WEST SET OF OBSERVATIONS

| Transit Time (mm.sss) | Transit Time (mm.mmm) | Swing Time (mm.mmm) | $\Delta t$ (secs) |
|---|---|---|---|
| 0.212 | +0.3533 | | |
| | | -3.1817 | |
| 3.321 | -3.5350 | | +21.396 |
| | | +3.5383 | |
| 7.044 | +7.0733 | | +21.294 |
| | | +3.1834 | |
| 10.154 | -10.2567 | | +21.294 |
| | | +3.5383 | |
| 13.477 | +13.7950 | | |
| | | $\Delta t_1$ = | +21.328 |

A negative sign for the swing time indicates the swing was to the right on the gyro scale. A positive sign for the swing time indicates the swing was to the left on the gyro scale.

1. The transit times from the stopwatch are listed in minutes, seconds, and tenths of a second, i.e., 4.181 is 4 minutes 18.1 seconds. Divide the seconds (18.1) by 60 and add to minutes to convert from mm.sss to mm.mmm.

example: 18.1/60 = .3017 min.
4 min. + .3017 min. = 4.3017 min.

The transit times have been converted to decimal minutes for ease in addition and subtraction.

2. The swing time is the difference between subsequent values of transit time. The value is positive if the swing was to the left, and negative if the swing was to the right.

3. The difference, or $\Delta t$, is the difference in time between subsequent values of the swing time. The sign is that of the larger value.

Amplitudes
10.92
12.98
10.92
12.88

mean = $a_1$ = $\overline{11.90}$ divisions

Original Plate Reading #2 = $N_2'$ = 119-28-20

**TABLE 3. OBSERVATION FIELD NOTES, EAST SET OF OBSERVATIONS**

| Transit Time (mm.sss) | Transit Time (mm.mmm) | Swing Time (mm.mmm) | $\Delta t$ (secs) |
|---|---|---|---|
| 0.264 | +0.4400 | | |
| | | -3.6500 | |
| 4.054 | -4.0900 | | -34.698 |
| | | +3.0717 | |
| 7.097 | +7.1617 | | -34.596 |
| | | -3.6483 | |
| 10.486 | -10.8100 | | -34.296 |
| | | +3.0767 | |
| 13.532 | +13.8867 | | |

mean $\overline{\Delta t_2 = -34.53}$

Amplitudes

12.18
9.38
12.18
9.38

$$\text{mean} = a_2 = \overline{10.78} \text{ divisions}$$

The following equation is then used to determine the proportionality constant "c", using the above data.

$$c = \frac{N_2'-N_1'}{(Wt_1 \times a_1) - (Wt_2 \times a_2)}$$

$$c = \frac{(119\text{-}28\text{-}20) - (118\text{-}58\text{-}20)}{(21.328 \times 11.9) - (-34.53 \times 10.78)}$$

$$c = \frac{30 \text{ min}}{626.0366 \text{ sec}} = 0.048 \text{ min/sec}$$

This technique does not require a new measurement of the proportionality constant for changes in latitudes as stated in the WILD manual.

The third step in calibrating the instrument is required because the spin axis of the gyro and the optical axis of the theodolite telescope do not coincide due to mechanical misalignment of the two instruments. A known first-order azimuth should be used for determining the calibration value "E". The accuracy of the known azimuth will be directly related to the final accuracy which can be obtained for your instrument. Therefore, if a first order azimuth is not available, the highest accuracy azimuth that is available should be used. Once some skill in using the gyro has been obtained, the gyro and theodolite should be set on a line of known azimuth, and the day spent making several measurements of the azimuth of the line. When the data is reduced, one difference between the true azimuth and the gyro azimuth will be due to the misalignment between the spin axes of the gyro and optical axis of the theodolite, and will be the calibration value "E".

## GYRO DATA REDUCTION
## TRANSIT METHOD
## SAMPLE CALCULATIONS

A GAK1 gyro has been obtained with a proportionality constant "c" of 0.048 and a correction constant "E" of -8' 26". A set of data taken with the gyro yields the following values:

Theodolite plate reading for gyro north: 136-06-19
Plate reading for the azimuth mark: 159-32-28

Seven transit time readings and two amplitude readings are made. Gyro north is first calculated. Gyro north is the direction of north as determined by the gyro exclusive of any misalignment between the gyro and the theodolite. The data are calculated as shown in Table 4.

## TABLE 4. OBSERVATION FIELD NOTES

| TRANSIT TIME (MM.SSS) | TRANSIT TIME (MM.MMM) | SWING TIME (MM.MMMM) | DIFFERENCE (M.MMMM) |
|---|---|---|---|
| (1) | (2) | (3) | (4) |
| 0.570 | 0.9500 | | |
| | | -3.3517 | |
| 4.181 | 4.3017 | | +0.0166 |
| | | +3.3683 | |
| 7.402 | 7.6700 | | +0.0150 |
| | | -3.3533 | |
| 11.014 | 11.0233 | | +0.0167 |
| | | +3.3700 | |
| 14.236 | 14.3933 | | +0.0168 |
| | | -3.3532 | |
| 17.4479 | 17.7465 | | +0.0158 |
| | | +3.3690 | |
| 21.0693 | 21.1155 | | |
| | | MEAN = | +0.0162 |

AMPLITUDES

10.58
10.63

MEAN = 10.61

The correction to the theodolite plate reading to determine gyro north is

Corr. (sec.) = c x mean difference x mean amplitude x 3600
Corr. = 0.048 x (+0.0162) x 10.61 x 3600 = +29.7 arc seconds.

Gyro North is 136-06-19.0
(+) Corr. 29.7

136-06-48.7

True North is 136-06-48.7
(-) 'E' 08-26.0

135-58-22.7

Finally, the azimuth of the mark is:

159-32-28.0
(-) 135-58-22.7

23-34-05.3