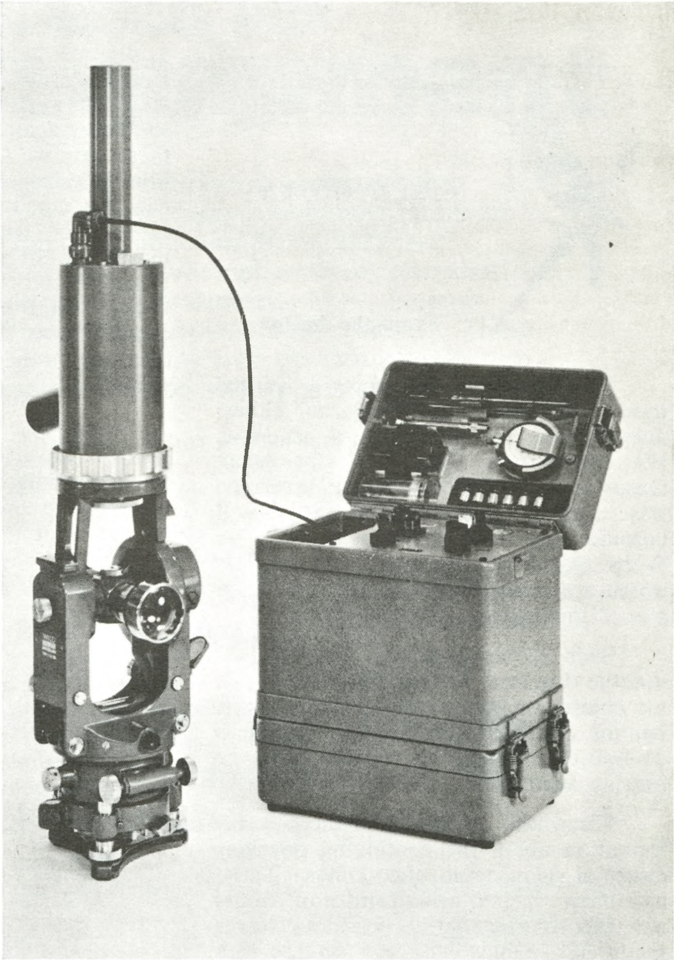
AN INTRODUCTION TO THE WILD GAK 1 GYRO ATTACHMENT



By T. P. JONES, OLS

The Wild GAK 1 Gyro Attachment was invented and developed by Professor Rellensmann of the Clausthal-Zellerfeld Mining Academy, of Clausthal, West Germany. It is manufactured by Wild Heerbrugg Ltd. of Heerbrugg, Switzerland, and distributed in this country by Wild Leitz Canada Ltd., and Norman Wade Company Ltd.

This instrument gives absolute orientation of a meridian without the necessity of astronomical observations. Clear weather, accurate clock time and nautical tables are not required to achieve a result.

It is capable of giving the true, or geographic azimuth with a standard deviation of plus or minus 20 seconds, in about 20 minutes of working time, at any time of the day or night.

Astronomical observations for longitude will still be necessary to convert the astronomical azimuths of this instrument, and others like it, to geodetic by Laplace's equation.

The GAK 1 is well suited to azimuth checks on long traverses; determination of directions for laying-out long, narrow constructions such as roads, railways, power lines, etc; orientation of transmitters, antennae for radar and other radio communications; checking of navigational devices; measurement of anomalies in geo-magnetic surveys; and perhaps the most useful purpose of all, the transfer of bearings between various levels, particularly in deep workings, such as the construction of all types of tunnels, and in mining operations.

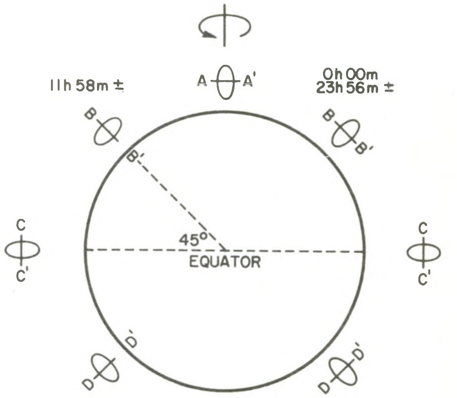
GYROSCOPIC PRINCIPLES

As copies of this magazine find their way to Australia and New Zealand, I have tried for the sake of politeness, if nothing else, to make the following descriptions, arguments and explanations applicable to both northern and southern hemispheres without making undue use of the word 'North'. If it does not occur anywhere else in this article, other than in this paragraph, you will know why.

A gyroscope consists of a rapidly spinning wheel mounted in gimbals that enable it to tilt freely in any direction. The momentum of such a wheel causes it to retain its attitude when the gimbals are tilted or moved. This property is known as gyroscopic inertia, or rigidity in space. Gyroscopes with the highest speed and the largest concentration of mass toward the rim of the wheel display the strongest gyroscopic inertia.

To put that contrapuntally, gyroscopic inertia depends on the angular velocity and the moment of inertia of the rotor, or on its angular momentum.

If, during the course of a small experiment, a spinning gyroscope were to be set upon a horizontal table at latitude 45°, with its spin axis horizontal and lying along a meridian, then after



CROSS-SECTION OF THE EARTH
FIG. I.

a little while an apparent change in its position would be observed.

The end nearest the pole would seem to tilt up and swing to the east as the earth rotated beneath it. About twelve hours after the beginning of the experiment, the spin axis would be pointing straight up. Twenty-three hours and fifty-six odd minutes after the beginning the spin axis would again be parallel to the table, and lie along the meridian.

One end of the spin axis would have moved through 180° in the vertical plane, 90° up and 90° down.

The change in azimuth of the spin axis is often referred to as 'drifting'. Sometimes 'tilting' and 'drifting' are collectively called 'apparent wander'.

If the gyroscope were on the same table, but with its spin axis lying in an east-west direction, a much greater tilt would seem to occur. After six hours it would be vertical, after twelve hours horizontal but upside down, then it would be vertical again before returning to its original state almost twenty-four hours later. One end of the spin axis would have moved through 360°.

At the risk of boring you, please now imagine the same table on the equator. In the first experiment with the spin axis along the meridian, no apparent wander would be observed; one end of the spin axis would move through zero degrees. In the second experiment, spin axis east-west, one end would move through 360°, as it did at latitude 45°.

If the gyroscope were located at either pole, there would be 360° of drift, and no tilt.

You will see in a minute that this is why these gyroscopes work better at the equator than anywhere else, and do not work at all at the poles.[9]

GYROSCOPIC PRECESSION?

Another property that the gyroscope enjoys is called by some 'gyroscopic precession'. I do not know why it is so called. I am familiar with lunisolar precession, planetary precession and general precession. Any similarities between the definitions of these astronomical precessions and this kind of gyroscopic precession eludes me.

Nevertheless, let us take a look at this strange anomaly called 'gyroscopic precession', that occurs in angular momentum gyros.

If, while a gyroscope were stationary, a weight, or a force, were applied to one end of its horizontal spin axis, the spin axis would tilt downwards as one would expect.

When the rotor is spinning at high speed, however, and the same force is applied in the same manner, the spin axis does not tilt downwards at all, but instead the whole unit starts to rotate horizontally about the centre of the gyro.

It also works in reverse. If a sideways pressure is applied at the same point on the end of the spin axis, the spin axis will tilt up or down.

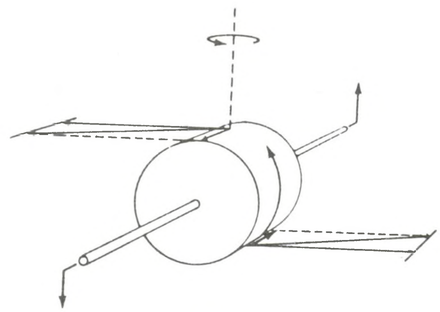


FIG. 2.

The reason for this is not that difficult to understand.

One definition of an angular momentum gyro refers to it as a system of particles that travel in curved paths. The curved paths are usually circular, each lying in parallel planes.

So long as the gyro is quietly sitting there, spinning away, everything is comfortably in equilibrium. Apply a small force that does not lie in a plane parallel to those referred to, and its angular momentum comes into play.

Two forces are now in effect, and remembering the old triangle of forces from high school physics, the 'resultant' force is the one that the gyro will obey.

A particle on the rim, while being affected slightly by the small force exerted on the spin axis, will be much more affected by the relatively very large angular momentum, which of course acts from off of the top and bottom of the rotor in the horizontal plane, and at right angles to the spin axis.

Note that if such a vertical force is continued on the end of the spin axis, at no time will the gyroscope back-up, or reverse its turn. If the force is removed, the gyro axis will stop rotating, but will not return to its original attitude. It will not 'precess', if there is such a word. Any standard, or uniform force applied to the spin axis will not make the spin axis seek the meridian. This so-called gyroscopic precession has nothing, or at least very little, to do with the meridian seeking capabilities of certain gyroscopes.[9]

Another way of looking at the behaviour of a gyroscope when a force is exerted upon it can be illustrated by considering a two frame gyro, as in Fig. 3.

If an attempt is made to rotate the base of such a gyro while it is spinning, (spin axis horizontal) a definite resistance will be felt. At the same time, the spin axis will tilt, and will continue to do so as long as the force is applied to the base. As the axis tilts, so the resistance to the base rotation will decrease. When the spin axis is vertical, the resistance will no longer be apparent.

The force being exerted on the base will now be in a plane parallel to the planes of the curved paths being followed by the particles on the rim of the spinning rotor.

All other things being equal, I figure that under these circumstances end 'A' of the spin axis in Fig. 3 will tilt up, and end 'B' will tilt down. Then the two forces acting on the gyroscope will not only be parallel, but also in the same anticlockwise direction. The external force will have melded with the much larger angular momentum, and the resultant force considered before will have disappeared.

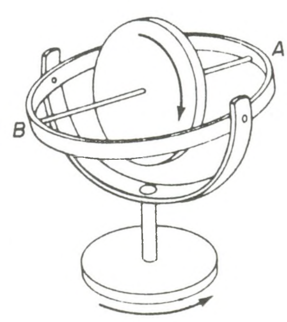


FIG. 3.

CONTROLLED GYROSCOPES

An unrestrained, or 'free' three-frame gyroscope, apart from being useful in the occasional scientific experiment, or as a child's toy, has little practical use.

In the controlled state, however, gyroscopes are widely used.

The GAK 1 is controlled in that it is suspended so that its spin axis must remain horizontal, but is free to rotate about its vertical axis.

A cross-section of the instrument is shown in Fig. 4, and a brief description of it follows.

The GAK 1 gyro attachment is 340 mm high, 85 mm in diameter, and weighs about 2 kg. It has basically two systems, the oscillating system and the supporting system.

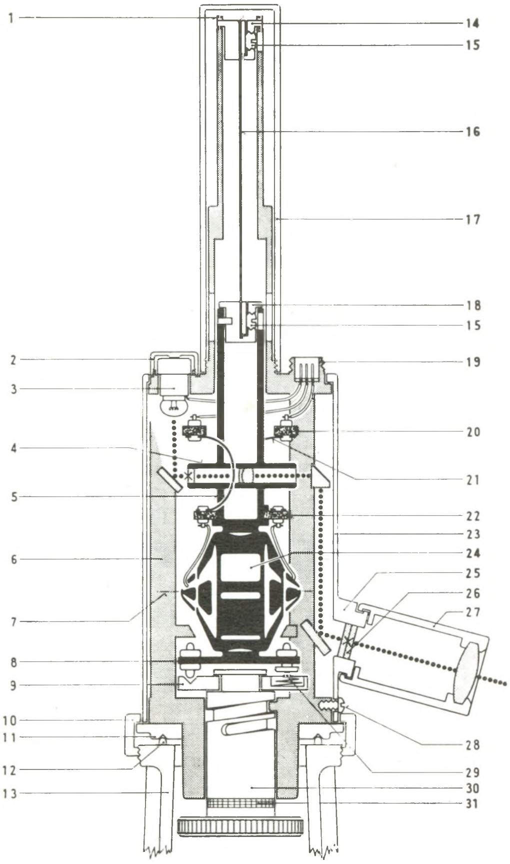


FIG. 4.

The oscillating system consists of the mast (5), the Perkin-Elmer type 831 gyro (24) and the damping plate (8). The mast also contains the electric leads (21) and the optical indicator system (4) with gyro mark. The whole oscillating system is suspended on the suspension tape (16).

The supporting system consists of a base plate with three columns (6) and a chimney like extension. At the bottom of the housing (23), inside the stub (25), is the reticle plate (26) with a graduated scale, on which the gyro mark is projected. The mask of the reticle plate is V shaped in the middle (Fig. 8). Each scale division of the plate corresponds to ten minutes of arc.

The gyro attachment is connected to a specially adapted T1A, T2 or T16 theodolite in such a way that, when in perfect adjustment, the gyro's spin axis (7) and the theodolite's line of sight lie in the same vertical plane when the gyro mark is centred on the zero of the scale.

The clamping plate (9) supports and centres the gyro when it is clamped. In addition, it dampens the gyro oscillations by friction on the damping plate with the clamping device (30) in the half open position.

The gyro motor is an asynchronous motor, which operates on 115V AC, 400 Hz. This voltage is obtained via a fully transistorised DC/AC converter. The battery has ten Ni/Cad cells giving a total of 12 V DC.

The operating temperature range of the unit is somewhat larger than the operating temperature range of the average land surveyor, extending from —40°C to +50°C.

RUNNING UP

It is important that the gyro is in the clamped position before it is started.

Once the starter switch is on, the running up period, which takes one to three minutes depending on the ambient temperature, puts the battery under maximum load. When the operating speed of 22,000 R.P.M. has been reached, power consumption falls away off, and the gyro may be released.

The initial impulse given to the gyro when releasing the clamp, and the angle between the gyro spin axis and the meridian, determine the amplitude of the oscillation of the spin axis about the meridian.

It is also important to remember that the quickly spinning gyro generates large forces. If it is handled carelessly, these forces can destroy the whole attachment.

SEEKING THE MERIDIAN

To see how this instrument will seek the geographic pole, I must again call upon your powers of imagination. I trust that the bizarre assumptions that I ask you to make will not detract from the explanations and arguments that follow.

This time, let us assume that the earth is stopped in space, that the GAK 1, at latitude 45°, is spinning away at 22,000 R.P.M., and that its spin axis is pointing exactly at the pole. So long as nothing disturbs this situation, the gyro will maintain its attitude, and continue to lie along the meridian.

Now let the earth start up!

The gyro now no longer points to the pole. It has already started drifting.

More importantly, even though it is still in a horizontal position, it is not 'comfortable' in this position. It wants to start climbing to a vertical position, as did the three-frame gyroscope that we had sitting on a table at this latitude.

The force of gravity is acting on one end of the spin axis, and the suspension system is acting on the other. The further around the earth moves, the stronger these forces become.

The gyro reacts to these increasing vertical forces on the ends of its spin axis by moving horizontally around its vertical axis to where these forces exert the least pressure, which of course is when the spin axis lies along the meridian.

When the gyro aligns itself with the meridian, however, its own mass inertia carries it beyond the meridian, and on into the adjacent quadrant. It will continue this swing until the gravitational forces build up again, to eventually slow it down, and send it back once more towards the meridian. The directional force causing this oscillation is directly proportional to the angle between the gyro's axis of angular momentum and the meridian plane, when the amplitude of the swing is small.[4]

I suggest that this phenomenon should be called 'gyroscopic precession', as this definition agrees more closely with the definition of the astronomic precessions than the one that was discussed earlier.

It will be apparent that the gyro, so long as it is operating at speed, will never stop swinging about the meridian.[9]

It also occurs to me, that as the direction of the spin axis of the gyro is affected indirectly by the eastward rotation of the earth, and that as there is always a certain lag to its oscillations, then by however a small amount, the mean line of the oscillations will always point slightly to the east of the pole.[9]

I think by now you will see that at the equator the forces acting on the spin axis of such a gyroscope would be stronger than anywhere else. You will also see that no such forces exist at the earth's poles, so that these gyroscopes will not operate there, as common sense dictates.

SWING TIME

As the gyro oscillates about the meridian, the suspension tape twists and untwists between the upper tape clamp (14) and the lower tape clamp (18). The torque in the suspension tape is far from negligible.[5]

The maximum latitude at which the GAK 1 can be expected to work reliably is 75°. This is due not only to the decreasing gravitational forces acting upon the spin axis, but also to the torque just mentioned.

The time of one oscillation of the gyro (from east to west and back to east again) is dependent upon the latitude of the gyroscope, and not upon the amplitude of the swing. A particular combination of gyro attachment plus converter will always have the same swing time at a particular latitude.

If the swing time at one latitude is known, the swing times at other latitudes are readily calculated. Swing times for a typical attachment/converter combination are shown in the table in Fig. 5.

As a matter of fact, between latitudes 60° and 75°, a latitude can be determined to within one minute of arc by timing the swing of one complete oscillation.

Latitude	Swing Time	Swing Time
	TU	TD
0°	6m 46.4s	6m 02.9s
30°	7m 16.7s	6m 23.9s
47°25'	8m 14.0s	7m 01.2s
60°	9m 34.7	7m 47.9s
75°	13m 18.8s	9m 27.3s

Fig. 5

A suitable amplitude for the oscillations when measuring is about one to three degrees. This can be obtained without difficulty by an experienced operator by the use of the damping plate and the three damping feelers, or brakes (29).

There are really two ways of letting the gyro oscillate about the meridian, and you will see from the table (Fig. 5) how the suspension tape torque effects these times.

Swing time TD is the time of a complete oscillation when the alidade and the attached gyro stay clamped in the approximate meridian. Time TD is affected by tape torque.

Swing time TU is not affected by this torque, because as the gyro swings, it is followed accurately with the alidade by keeping the gyro mark centred at all times in the v on the reticle plate. This is called 'tracking' by some.[3] For this swing time, a whole oscillation period depends only on the horizontal component of the earth's rotation.

Apart from the instrument constant, which depends upon the state of the adjustment of the instrument, the direction of the middle position of the oscillations of the gyro's spin axis to all intents and purposes corresponds to the line of sight of the telescope along the geographic meridian.

Four observational methods with the gyro attachment are now described as briefly as possible (I don't want to rewrite the owner's manual). The first two take little time in the field, and give an approximate result. The last two methods are for more precise location of the meridian.

QUARTER TIME METHOD

The latitude, and the corresponding swing time, TU, for the particular instrument must be known to use this method. Basically, a stop watch is started at one extremity of a swing. The gyro mark is followed with the alidade until one quarter of the swing time has passed, and the alidade is then clamped.

The line of sight of the telescope will point along the meridian to within the following limits, which are dependent upon the amplitude of the swing:—

As the exact time at the extremity of a swing is difficult to judge, two times are taken as indicated in Fig. 6, and the quarter swing time added to the mean of these.

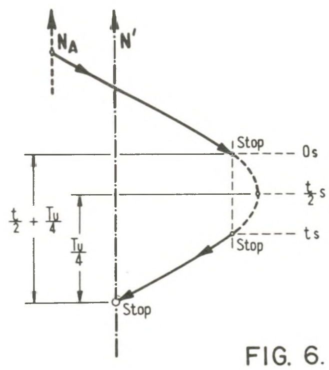


FIG. 6.

REVERSAL POINTS METHOD (Approx.)

After the gyro has been released, the oscillation of the gyro mark is followed up smoothly by the alidade, with the horizontal clamp open, so that the moving mark is always in the v-shaped index. The mark slows down as it approaches a reversal point and at the point itself is at a standstill for a short time. At this instant the mark and the v must be coincident, and the horizontal circle read.

The mark is then followed up immediately (so that torque in the suspension tape is kept to a minimum) in the opposite direction until the second reversal point is reached and the horizontal circle is read again.

The mean of these two readings should give the meridian to within two or three minutes of arc.

REVERSAL POINT METHOD (Precise)

This is practically the same as the above.

The amplitude of the swing, however, is kept to about two degrees, and the alidade, horizontal clamp closed, is made to follow the gyro mark with an especially fitted, extra long, upper slow motion screw.

For highest accuracy, four to six reversal points should be observed.

Because of damping, instead of a simple arithmetic mean, Wild Heerbrugg Ltd. suggest that a Schuler's mean be calculated. The Schuler's mean is shown as N^1 and N^2 in Fig. 7, which hopefully is self-explanatory.

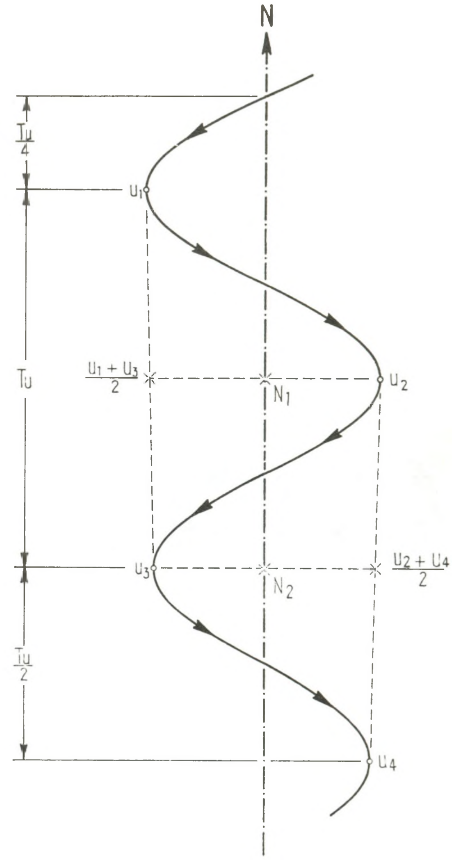


FIG. 7.

TRANSIT METHOD

The telescope is set to point within ten minutes of arc of the meridian . The telescope then remains clamped in this approximate direction throughout the measurement. The horizontal circle reading is noted.

When the gyro is released, the amplitude of the swing is noted from the gyro mark on the reticle plate, and the times between successive transits of the mark through the v on the reticle plate are also noted.

The amplitude readings need only to be made once. For the highest accuracy, four or five transits should be timed.

Fig. 8 illustrates the situation. The telescope is situate on line N^1, the meridian is on line N. From the data, you will agree that the location of line N relative to line N^1 can be calculated.

The calculations are complicated somewhat by the fact that everything in the attachment/theodolite combination cannot be in perfect adjustment. For example, when the suspension tape is hanging straight, and free from twists, the spin axis of the gyro and the line of sight of the telescope are probably not in the same vertical plane; at the same time, the gyro mark is probably not centered in the v on the reticle scale; therefore the tape torque has affected the

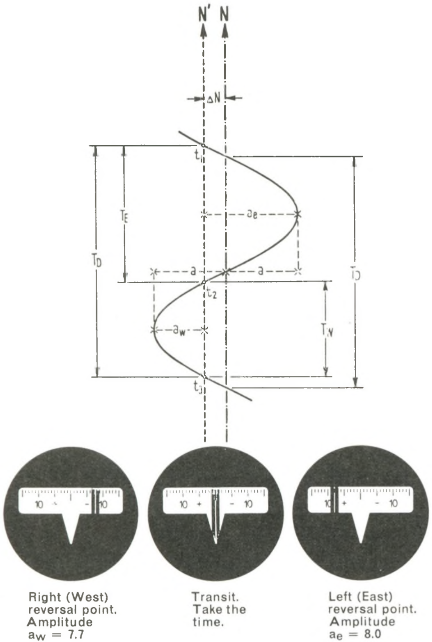


FIG. 8.

readings on one side of the oscillations more than the readings on the other.

Specially printed forms provided by Wild-Heerbrugg, however, ensure that the reductions are carried out in an orderly manner. They don't appear to be much more complicated than a page of stadia notes, and are well within the capabilities of anyone reading this.

Average times to achieve a result, according to the Company and not including reductions, are as follows:—

	Standard Deviation (m.s.e.)	Average Time Required
Setting up and preliminary observations		4 min.
Running up and approximate orientation	±3′	6 min.
Transit or Reversal Point Method	±20″	10 min.
Total		20 min.

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9. This statement is mine. You must take it for what you think it is worth. It is open for discussion.