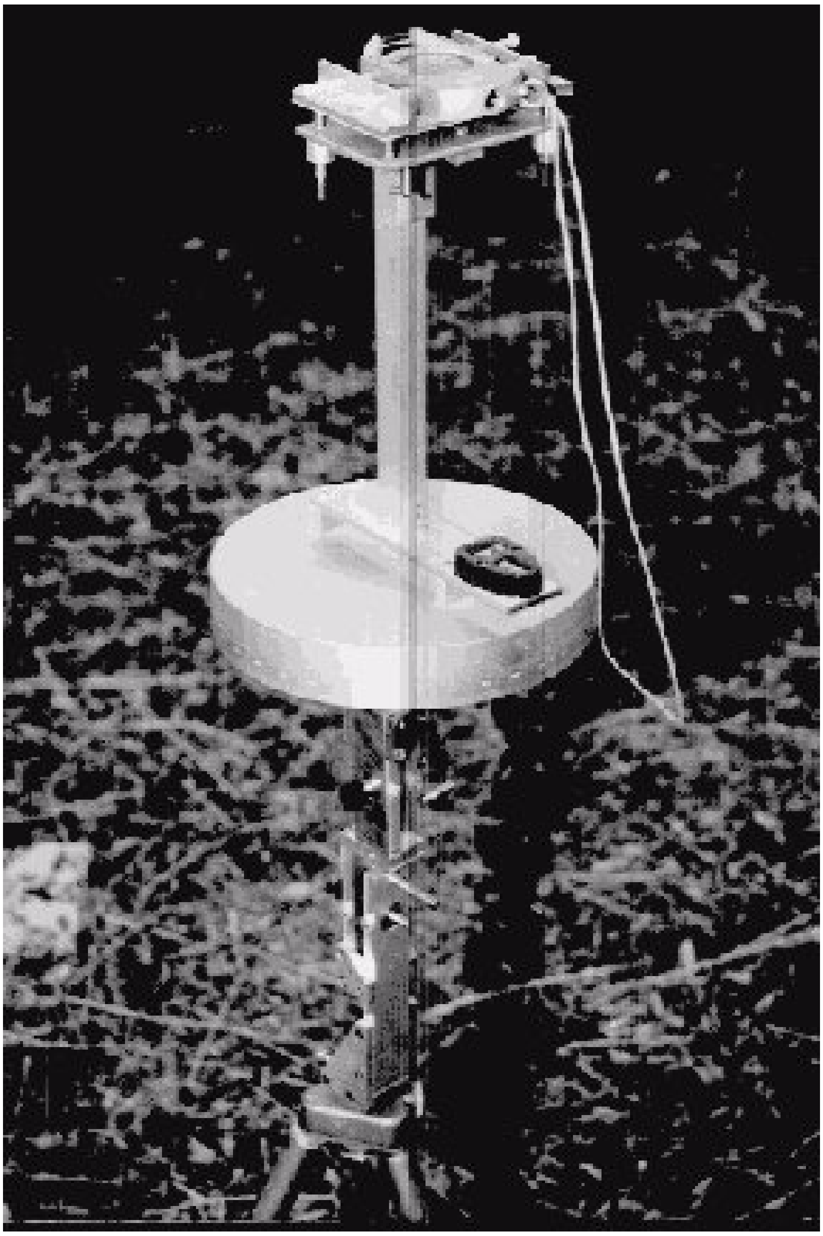
ISSN: 1361-8962

Issue 21

Compass Points

September 1998

BCRA



Intrinsic Errors in Suunto Instruments

Instrument Lighting

Errors in Radio Location

The Journal of the BCRA Cave Surveying Group

COMPASS POINTS INFO

Compass Points is published quarterly in March, June, September and December. The Surveying Group is a Special Interest Group of the British Cave Research Association. Information sheets about the CSG are available. Please send an SAE or Post Office International Reply Coupon.

NOTES FOR CONTRIBUTORS

Articles can be on paper, but the preferred format is ASCII text files with paragraph breaks. If articles are particularly technical (i.e. contain lots of sums) then *Microsoft Word* documents (up to version 7.0) are probably best. We are able to cope with most common PC word processor formats. We are able to accept disks from other machines, but please check first. We can accept most common graphics formats, but vector graphic formats are much preferred to bit-mapped formats for diagrams. Photographs should be prints, or well-scanned photos supplied in any common bitmap format. It is the responsibility of contributing authors to clear copyright and acknowledgement matters for any material previously published elsewhere.

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PUBLISHED BY

The CAVE SURVEYING GROUP of the BCRA. BCRA is a registered charity.

OBJECTIVES OF THE GROUP

The group aims, by means of a regular Journal, other publications and meetings, to disseminate information about, and develop new techniques for, cave surveying.

BCRA ADMINISTRATOR

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ANNUAL SUBSCRIPTION RATES

Publication	U.K.	Europe (air) & World: surface	World: Airmail
Compass Points	**4.50**	**6.00**	**8.00**

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COMPASS POINTS LOGO

courtesy of Doug Dotson, Speleotechnologies.

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Cover : Lang Brod's device for measuring the deadband of Suunto compasses.

Editorial

Apologies for the last issue being rather late (what do you mean, you didn't even notice!), and for the back page being blank, thus rather spoiling David Gibson's Radiolocation article. As you can tell we are still getting used to doing our own printing and distribution. The printing errors were entirely due to the printers. We've beaten them over the head, so I hope they'll get it right for this issue. Timeliness is subject to the vagaries of the editor's and secretary's holiday and DIY schedules, but we'll endeavour to be less than a month late in future!

CSG Admin

Oddly enough we haven't been exactly crushed by the throng of prospective new committee members, so there is still room for anyone who'd like to influence the direction of the group, or just help out with envelope stuffing (ideally you'll live near Bristol for the latter).

Forthcoming Events

BCRA Conference - Hidden Earth

This is in Southport this year. The CSG will be holding it's AGM there, as usual, and will have a stand showing the latest software and the group's activities. There will be a 'software workshop' where you can try out the range of currently available survey software. Also there is the opportunity to enter for the Arthur Butcher Survey award. Bring all your surveys, even computer-generated ones and display them. A taster of the future of 3D cave modelling will also be on display.

Autumn CSG field Meet

The CSG will be holding it's first Derbyshire field meet on the weekend of the $17^{th}/18^{th}$ October based at the Orpheus Caving Hut.

All surveyors are welcome, novice or experienced. Training will be provided for anyone who wants it, and we expect to visit a few interesting caves or mines in the area. We'd also really like to hear from surveyors in the area about anything they'd like to do or discuss.

Survey Software will be available for hands-on demonstrations, and a selection of instruments will be there for people to try out, including the better Suunto and Silva devices.

There is accommodation for 18, although this may be shared with other visiting cavers. Cost is £3.00 per night unless you are a member. The contact for this meet is Andy Atkinson (address in masthead).

Secretary's Note

Andrew Atkinson

Info from the CSG secretary on how membership renewals and Compass Points distribution are dealt with, now that membership and CP distribution are no longer being done for us by CREG.

I am now, after a couple of goes, getting the hang of what I am meant to do, so let me first apologise for any mistakes that I have inevitably made. Let me explain how I am dealing with the sending out of Compass Points. Essentially if you renew with the renewal notice you will receive your CP four times a year. This is what I would prefer as it makes my life easier and saves the CSG money. If you renew on the final reminder, issued after your final issue, you will not receive that issue of CP (the one you got a final reminder instead of) until the following issue is sent out (when you will get two).

I feel that it would be more convenient if you could pay your CSG subscription at the same time as your BCRA membership. This is possible at the moment; both I and the BCRA centrally will take the subscriptions. However, as usual, life is not that simple. To be able to pay them together they need to have the same renewal date. I can adjust the amount payable to CSG so that these dates will align in future. However to be able to do this I need to know when your BCRA membership is renewed (and your number including the letter would help), so if you could please make sure that this is completed on your next renewal form, the renewal after that should appear with the option of paying an amount to align the renewals. This would also mean that it would be possible to pay by standing order and if a covenant was also filled in BCRA could get the tax back (Obviously this will have conditions that I suppose I am meant to write in here, so I will substitute for this the all encompassing phase: subject to the usual conditions.)

Unfortunately, this will take some time and if you would prefer it to happen more quickly let me know the above information before your next renewal. I hope all that made sense.

Finally, I would like to apologise to you all for the poor quality of the last issue (especially the final missing page). I would have had it reprinted but I was going away with work, and you would most probably still be waiting for it. The printers excuse is that it must have been enlarged by a small amount therefore shifting some of it to the edge of the page. Anyway they have paid a 50% refund and promised that it would not happen again.

Could you teach Surveying?

Andrew Atkinson

From time to time, I have had requests for people who could teach surveying to others at various levels. So far, all the requests have been close to me so I have undertaken it. If anyone would be willing to help out with these very occasional requests, it would be nice if they could tell me so that I can make a list. Then, if I get a request from another part of the county, I could pass it on. Address and email in the small print at the beginning of CP.

SNIPPETS

Not a lot happening in surveyor-land this quarter so far as I have been made aware. About all I can report is that at the NSS convention in the U.S. Bob Thrun gave a talk about his tests showing the problems of sequential, as opposed to simultaneous loop closures. This was followed by a talk explaining the advantages of sequential closures. This is an interesting subject and I hope to publish more details here in due course.

Compass Software Update

1. Viewer. The Viewer now has a special option that allows you to display a "Shadow Box" around the cave. With the Shadow Box options, the program draws a box around the cave and mirrors the cave on the walls of the box. The option makes it easier to see 3D aspects of the cave. The program gives lots of options for controlling which walls are mirrored and the placement of the walls.

2. Viewer. The Viewer can now save bitmap images of the screen at high resolutions up to 600 dot per inch. This is useful when you are publishing cave images. High-resolution images give smooth lines and images on a printed page.

3. Viewer. The Viewer can save all the settings that go with a particular view of a cave. These settings are called "Views." Views can be saved and restored. Dozens of views can be saved to a file. This means that even the most complicated settings

can be restored with a few mouse clicks. This makes it easy to do presentations and work on special projects.

4. Viewer. Up until now, all the passage modelling modes displayed 2D images of the passages. This was necessary for the spline curve modelling and it also allowed the images to display faster. Passage modelling now has a mode that displays full 3D polygons of the cave passages. It also creates more accurate display when doing 3D rotations. You also have the choice of displaying the passage outlines as diamond or rectangular shapes.

5. Viewer. You can now display stereo views of the passage wall modelling. This allows you to see the dimensions of rooms and passages in 3D.

6. Viewer. In the past, the Viewer would place passage wall marks at both the From and To stations. Since most stations are both a From and To station, this puts two sets of markers at each station. The new feature gives you the option of putting only one set of markers at each station. This makes the markings less confusing and easier to use for map drawing.

7. Project Manager. You can now enter fixed station location in either longitude/latitude or UTM. Long/Lat. can be entered in either decimal degrees or degrees, minutes, seconds. The program allows you convert easily between the two units.

8. All Windows COMPASS programs now support 12 character station names. The only reason they are not larger than 12 characters is to try to maintain a minimum amount of compatibility with DOS version. Because of the limitation of DOS memory, the DOS version will not be able to move much beyond 8 characters.

9. Viewer. There is now an option that moves the Measurement Cursors to the nearest survey station. This makes it easy measure 3D distances between stations.

10. Viewer. The Viewer now shows the comments and date associated with each survey. This information is displayed in the Find Survey dialog box. Comments can also be searched for any matching or partially matching string.

11. Viewer. The Viewer can now display the angle of cave rotation in three ways. The first shows the number of degrees the cave has been rotated. The second shows the angle you are looking toward as the cave is viewed and the third shows the angle the cave is viewed from.

12. View/CaveBase. The Viewer and CaveBase can now display the query results by colouring shot nearest the station. This is useful when the marking with a symbol would create a crowded and cluttered display.

13. Project Manager. The Project Manager has a new "Project Creation Wizard" which guides you through all the steps of creating a new cave project.

14. The web page has lots of new images that demonstrate the latest features.

There are also 15 other improvements and bug fixes.

Press Roundup

The American Compass & Tape journal is looking very good under the editorship of Pat Kambesis. Two issues have plopped through the door since the last CP, and they contain some very good material.

Compass & Tape: Vol 13, Number2 - Issue 42

Call for papers for 1998 NSS convention

Survey and Cartography Section Meeting, June 26 1997, by George Dasher. Minutes of the meeting - nothing very exciting.

1997 Cartography Salon Awards, by George Dasher. Ten surveys by Kevin and Carlene Allred, Bert Ashbrook, Bill Balfour, Brent Aulenbach and Walt Hamm got honourable mentions. Two surveys by Pat Kambesis got Merit awards. Medals were won by Hazel Barton for ‘Cave Creek Caverns, Park County, Colorado’ and Kevin and Carlene Allred & Bob Richards for ‘Kazamura Cave Atlas, Island of Hawaii’

Computer Graphics - A Freehand Way to Generate and Gisplay Cave Maps, by Bob Richards. An interesting article describing the use of Macromedia’s Freehand software for drawing cave surveys. Bob is a professional graphics person in a company that produces geological maps. He has used all the well-known graphics packages - AutoCad, CorelDraw, Illustrator, and Canvas before settling on Freehand as the best of the bunch for Drawing. It is available for both Mac and PC.

He first draws the sketches around the line plot and then scans the result in on as many sheets as it takes and sticks it back together in the computer to give a template to draw around. This is done at low resolution as it not used in the final image. The resulting image is traced in Freehand to get a nice vector image. He also describes how to use coloured blends to enhance the survey. You can even add scanned photos of relevant places in the cave. Bob was the first person to win a survey salon medal with a computer-drawn map. A couple of his surveys are printed (in colour!) showing how effective these techniques can be.

On Surveying Underwater Caves, by Jim Coke. Jim describes the extra problems that diving presents to the surveyor - especially severe time limits. This makes the survey of Cenote Mayan Blue, an 8184m long and 28m deep underwater cave in Quintana Roo, Mexico, a remarkable achievement, which has taken 350 dives and 1050 hours of surveying. A very nice A3 pullout survey is included.

He describes the instruments: Suunto compass, marked to 5 degrees, but can be estimated to 1 degree, digital depth gauge reading to 1 foot, so not very accurate over short legs. Marking the surface level for each dive is very important as it can vary. When surveying with a tape one diver records the bearing, the other the tape reading, and both record the depth, so that the two incomplete datasets can be turned into one complete dataset on the surface. Tim measured over 150 ‘one hundred foot’ sections of knotted line in previously surveyed caves and found that these were always 1 to 5 feet short, strongly suggesting that caves surveyed by knotted lines are up to 10% longer than those surveyed by tape.

In the end 9 of the 36 loops had to be resurveyed to get acceptable accuracy, and all the errors on bad loops were found to be due to compass readings. They used a standard form for surveys in the project to ensure that surveys tied-in properly. The passage detail is done on later dives, using slates with pre-drawn centrelines. The survey took several years, and has, of course led to new discoveries in all sections, eventually quadrupling its length to make it the third longest underwater cave in the world.

Notes for Cave surveyors on the Earth's Magnetic field, and orienting cave surveys to True North using the USGS GEOMAG Program, by Ira D. Sasowsky. Explanation of the earth's magnetic field, and how to use the GEOMAG program via a web browser, telnet, dial-up, email, phone or post to get declinations for any time and place.

Mapping Equipment for Wet Caves, by Philip L. Moss. Philip describes that his Silva 'type 80' has been very reliable in some miserable caving but that a Suunto prismatic 'twin' lasted only one trip before getting mud in the capsules and the lens getting water in it so you couldn't read anything - useless. A waterproof plastic Brunton has done quite well with limited usage.

He recommends (the unfortunately discontinued) Avery tear-proof paper over 'rite-in-the-rain' rag paper. Nelgene Polypaper is durable, but the notes on it tend to get washed off, so that's not too great either.

Cartographers' Corner, by Pat Kambesis. Pat examines interesting ways of showing cross-sections and elevations. A complex section of Mammoth with 6 passages overlying each other has one big cross-section for them all showing their relative positions as well as their shapes.

A 1961 map of Fisher's Fissure labels cross-sections on the plan in the usual way and shows them by the side of the depth scale showing their heights neatly too. Similarly the Gruta del Café, Mexico survey has the cross-sections drawn next to their location on the elevation, rather than the plan.

In the Palace Cave map John Brooks has referenced all the cross sections to a zero-datum so their relative heights are clear (the cave is basically horizontal).

Compass and Tape, Vol 13 , Number 3 - Issue 43.

Section Business/Letters to the editor.

Magnetic Influences upon Compass Accuracy, by Doug Strait. Doug has done the same tests that Andy Legg published in CP 8, pp7-8, but for US items of gear. He finds that some items can deviate a compass 35 degrees, and that for nearly all lights it was the batteries in them that had the effect, rather than the lights themselves. Other interesting facts are that to show no deviation your compass needs to be 10 feet from 2m tall chainlink fence, 18" from a fridge magnet, 11" from 4AA cells and 2" from a spit. He also discovered that alkaline cells are weakly magnetized, although the degree varied by a factor of 10 between different ones. This is presumed to be due to the manufacturing process for the steel casings.

Errors in the Suunto Compass used for Cave Surveying, by Lang Brod. Examination of the intrinsic and mechanical errors in several Suunto compasses. Reprinted in this issue of CP.

Hourly Variation of Magnetic Declination, by Robert Thrun. The same article that appeared in CP 18, p12.

Surveying and the Role of Geological Data, by Dr. A.R. Farrant. Reprinted from CP18, pp 4-6.

Two AutoCAD Linetypes for Cave Cartography, by Bert Ashbrook. Details of how to create an AutoCAD 'complex line type' to make the drawing of floor and ceiling steps much quicker and easier.

Ceiling Height Determination in Large Rooms with Common Cave Surveying Equipment, by Jim Glock. A technique for finding the height of an inaccessible ceiling. The difficult bit is getting an accurate vertical to sight on, and this is best achieved by hanging a narrow-beam torch from a string and then spinning it. The centre of the circle on the roof will be directly above the torch. The trigonometry required is also presented.

Report on UIS Symbols list for Cave Survey, submitted by Garry Petrie. Some of the symbols that were agreed at the UIS congress in Switzerland last year, along with some comments about the more contentious ones, based on Wookey's report in CP17.

LETTERS

Guy Van Rentergem (SC Avalon)

Hello, I'm using a Leica Disto nearly everyday in my professional life for more than two years now. I use it to measure buildings. And at the weekends I use it quite often to map caves here in Belgium. I even took it to Jamaica to survey Potoo Hole on the Portland Ridge.

I just want to say that the machine is more or less caver proof !! All right, it won't survive a drop of 20 metres but a drop from 1 metre seems OK. And it won't survive a dive but is very robust. After all, a compass or clinometer is also handled with some care. It is very practical and reliable for surveying caves. As proof: I never take a tape measure with me, even on expeditions. I use it in combination with a digital laser clinometer.

Surveying has changed for me!!!! Now I'm looking for a reliable digital compass. Has someone here any ideas ?

Leica has now a new cheaper (250 US$ less) model: the Disto Basic. This model is in my opinion not so caver-proof as the old model. It has a big plastic lens and the edges aren't protected anymore by a rubber cover. But it works faster and has as an option a special lens to find the laserdot.

This option is very handy when surveying on the surface. I will test this new model this summer in Jamaica. By the way, Hilti has now also a laser range-finder, it is more costly than the Basic. It looks good and feels very robust and it is based on the same electronics as the Leica basic. And Bosch has also one, but I haven't seen it yet.

Many greetings from Belgium,

[John Lyles has confirmed that the Hilti PD10 is almost identical to the Lieca Disto-Basic, and is very probably the same instrument re-packaged - Ed.]

Surveying Underwater Caves - some further information

John Cordingley

Abstract: The techniques described in 'Surveying Underwater Caves' in CP16 have been put into practice in a large system. The results from the first major loop closure have shown that the system works very well.

Compass Points 16 (June 1997) pages 9-12 contains an article which reviews the basic survey methods in use by Cave Diving Group members in the United Kingdom. One of its main aims was to clarify the standards of accuracy which divers can be expected to achieve, particularly as many dry cavers seem to view our amphibious efforts merely as untrustworthy "add-ons" to supplement their cartographic masterpieces! Since the above article was published a lot of data collection has taken place in Keld Head, North Yorkshire (Britain's most important underwater cave). Of the 7.5km or so of explored underwater passages here, some 2.4km are now resurveyed. The main lines have been mapped using the new accurate technique (see "Special Underwater Surveying Methods" in the above reference).

One advantage of Keld Head when developing ways to survey whilst diving is the existence of several loops. I was very keen to find out how accurately (or otherwise) the work is progressing so the opportunity has been taken to close a loop around the two main up-valley passages (known as "The Dark Side" and "Kingsdale Passage"). The distance around this loop was found to be 1077m and we were delighted to find that the misclosure was only 1%. The total diving time spent actually collecting these particular data was only about 5 hours (see C.D.G Newsletter 128, July 1998, pages 12-18). Thus, a significant advance in survey quality, achieved in a relatively short time spent underwater, seems to be possible.

The Keld Head survey project is being continued whenever the weather allows. I must record my thanks here both to Pete Grant and Ray Duffy who have done all the number crunching (thereby allowing me to concentrate on the diving). We have been using "Survex" to process the information and it has proved to be ideal for handling data collected underwater (i.e. entered in a different format from conventional survey data). The information that Survex has quickly given us (sometimes before the survey slate had even stopped dripping!) has proved invaluable - it contributed to the discovery of 400m of large new passages in May this year for example. A small printout of the Keld Head survey to date accompanies these notes; if anyone would like further information please feel welcome to contact me via j.n.c@btinternet.com.

Errors In The Suunto Compass Used For Cave Surveying

Lang Brod

Many recent articles on compass errors have dealt with errors encountered in the utilisation of hand-held compasses in an underground environment. Furthermore, many of the articles treat errors made during the use of Suunto compasses, which have become a popular cave surveying compass in recent years. Errors have been further subdivided into small random errors arising during sighting the target or reading the compass, and larger errors (blunders), resulting from gross misreading of the compass dial or problems in transcribing the reading. The impression conveyed by these articles is that the authors consider all errors to be external to the compass. This attitude is understandable; the drum dial and the superimposed cursor of the Suunto compass are readily visible, and it is easy to read the dial to the nearest half-degree. Such apparently accurate readings may in fact mask inherent errors, which may not be evident to the user.

Over 20 years ago, in 1974, I began an attempt to measure internal compass errors in preparation for a proposed NSS mapping manual. For that purpose, I constructed a small non-magnetic rotary table calibrated in one-degree increments, topped by a small adjustable platform upon which a compass can be fastened. The table can be levelled so that its rotation axis is vertical; the platform can then be adjusted so that the compass rotates in a plane. In use, the turntable is turned so that it reads approximately zero when the compass is reading zero degrees magnetic. The turntable is then rotated until the compass reads exactly 005 degrees, and the resulting turntable position is then read and recorded. This procedure is repeated until the full 360 degrees has been covered. Data reduction simply consists of subtracting the compass reading from the corresponding table reading.

If the turntable and compass were both perfect, the difference between the two readings would be constant, or zero. This difference in the general case is not constant, and the variation in the difference permits an assessment of compass error. It should be noted that the calculated difference tells nothing about the relation of compass zero to magnetic north. Such a relationship can, in principle, be determined by sighting on a distant landmark from a known position.

The non-magnetic turntable is constructed of two aluminium discs 8 inches in diameter by 3/4 inch thick; the upper disc rotates on a closely fitting brass shaft set in the lower disc. The lower, fixed disc has been graduated from zero to 360 degrees in one-degree increments; the other disc bears a single cursor line. The degree scale markings are accurate to +/-0.1 degree and can be read to an accuracy of +/- 0.1 degree; the compass can be read to an accuracy of about 0.2 degree. Assuming the errors are random, the root mean square error can be calculated as about 0.25 degree. In as much as the angular difference variation for many compasses is greater than 0.25 degree, that variation is a valid measure of the compass error.

Tests on several Suunto compasses using this equipment reveal that there are two components of compass error. The first is a systematic error, which is a function of dial reading, and which appears to be repeatable. Many years ago, John Walker described a systematic error encountered in a Brunton compass. The error was caused by a bent pivot pin, possibly caused when the compass was dropped, displacing the pivot from the centre of the dial. In such a condition, the compass reads correctly in only two positions 180 degrees apart, and which has maximum positive and negative errors at 90 degrees from the zero-error positions. A similar systematic error can occur in the Suunto compass if the centre of the drum at the pivot is not perfectly coincident with the centre of the degree graduations on the periphery of the drum. Inasmuch as the centring is the result of a manufacturing operation, it is potentially subject to error. Tests performed on several Suunto compasses indicate that there appears to be a small systematic error present in all of them. Calculations indicate that a centering error of only 0.1mm (0.004 inch) will produce an error of +/-0.3 degree, for a total error excursion of O.6 degree.

Superimposed on the systematic error is a second error, random in nature, which is the result of a defect termed “deadband”. The force which causes a compass needle to align with the Earth’s magnetic field is proportional to the sine of the angular difference between the field and the needle, which goes to zero as the angular difference goes to zero (2). As the compass needle or drum swings into alignment, the force causing the motion decreases, so that ultimately, at some position, the force is equal to the pivot friction and the motion ceases. Thus, there is a small angular range, symmetric about the null position, where the needle or drum ceases to turn; this region is the deadband, as shown in Figure 1.

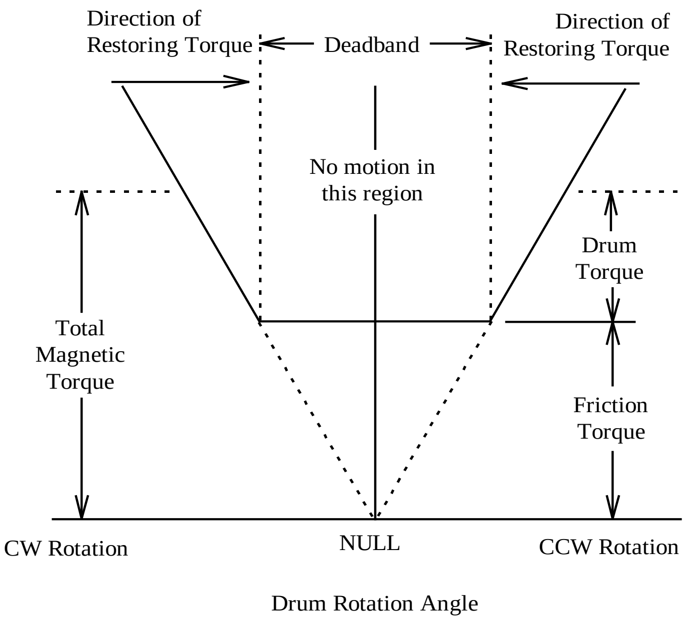

Figure 1 - Compass Drum Rotation vs. Torques

All good compasses, including the Suunto, utilise a jewel pivot bearing to minimise friction and reduce deadband to a very small angle. The bearing, which is fastened to the drum centre, is supported on a small steel pivot pin which has been sharpened to a point. The point is actually a small spherical surface which is sufficiently tiny to reduce friction to a minimum but large enough to support the weight and the forces acting on the jewel bearing without being deformed. In the Brunton compass, the pivot pin is protected by a mechanism, which lifts the needle off the pivot when the lid is closed. The Suunto instruments do not have such a protective device and may not need it, because of the damping liquid support.

In the undamped Brunton compass, the inertia of the needle will cause it to swing past the null position and overshoot until the increasing counter-torque causes it to stop and begin swinging in the opposite direction. The damping liquid in the Suunto keeps the overshoot from occurring.

Details of Compass Tests

The testing protocol was developed over time during a number of repeated tests designed to gain experience. First, the compass was mounted in the test fixture, with the compass-magnifying window on the rear side of the clamping fixture, above the cursor line on the upper disc. The tripod was then rotated with the compass stationary so that the cursor line on the upper disc was approximately coincident with 000 degrees on the lower disc when the compass was aligned with magnetic north. The tripod is then carefully adjusted so that the rotating disc is accurately levelled; next the compass is levelled with adjusting screws on the compass clamping fixture. After levelling, the compass is ready for testing.

The test begins by rotating the compass about its vertical axis until the dial reads about 005 degrees and then leaving it quiet until rotation has stopped. The compass is then slowly turned in one direction until the dial reads 000 degrees. Because of damping, the compass drum dial will rotate with diminishing speed until it comes to rest. If the drum dial falls short of 000 degrees, it can be carefully rotated a small incremental angle to bring it to the correct reading. However, if the drum dial overshoots 000 degrees, it is necessary to go back to 005 degrees and allow the drum dial to come to rest before restarting the test. Once the compass reads exactly 000 degrees, the turntable reading for that position is recorded.

For the next step, the compass is again unidirectionally rotated from 000 to exactly 005 degrees, again allowing no overshoot, and the corresponding turntable reading for that angle is recorded. For the third reading, the compass is aligned to about 015 degrees and allowed to come to rest before carefully turning it back to 010 degrees. In this manner, each five-degree increment is approached from an alternating direction so that the deadband can be determined. When the full 360 range of the compass has been tested in this way, the difference between the compass reading and the turntable reading is calculated, and the difference angle is plotted as a function of compass angle.

Tests utilising the rotary table were performed on 8 KB-14/360 Suunto compasses of various ages and construction, as listed below:

1. old KB-14/360, S/N 706088, tested March, 1989
2. new KB-14/360, S/N 636557, tested March, 1989
3. new KB-14/360, S/N 945389, tested March, 1990
4. new KB-14/360, S/N 034254, tested c. 1991
5. new KB-14/360Q, S/N 033808, tested October, 1992
6. new KB-14/360, S/N 106495, tested c. 1992
7. new KB-14/360, S/N 118397, tested June, 1993
8. new KB-14/360, S/N 130571, tested March, 1996

Results of these tests are plotted in figures 2 and 3. In addition, three tests were performed on Suunto plastic compasses, as shown in figure 5.

It is certainly difficult to draw many conclusions from such a small sample, but a few conclusions may be possible. The seven new KB-14 metal compasses all exhibited very good performance, with minimal deadband and most had little systematic error. In contrast, the old KB-14 showed a larger amount of deadband and apparently some systematic error also. It is probable that this compass pivot has been somewhat blunted by impacts during usage, resulting in greater pivot friction.

Both new KB-20 plastic compasses appear to have an amount of deadband error I would consider excessive. If this error is really characteristic of this type of compass, it should not be used for cave surveying. The lack of a serial number on these compasses may indicate that they are not manufactured to be as accurate as the KB-14. Interestingly, the old KB-20 with much cave usage had smaller deadband error than the two newer compasses.

At about the time I was testing compass seven, a Sisteco compass/clinometer was submitted to me for testing, and I was interested in comparing the Sisteco compass with the Suuntos. The Sisteco combination instrument is housed in an aluminium block about twice as long as used for a Suunto compass or clinometer, and each part is essentially identical to the Suunto counterpart. The test of the compass (figure 5) showed that the systematic error was about 1.3 degrees, somewhat high but certainly comparable with the sixth instrument tested. What was interesting was that the deadband error was surprisingly low, averaging roughly about 0.1 degree, at the very limit of resolution for this type of error.

The one aspect of this compass that did appear to be different was a noticeable tilt of the dial, despite the levelling of the compass body. I determined the approximate compass angle at the maximum tilt condition and then turned the compass 180 degrees so that the tilt was a maximum in the opposite direction. I then tilted the compass body until the drum dial was tilted at about the same angle as previously with the aid of a plate and a shim of known thickness. The total tilt required for compensation was about 5 degrees, corresponding to a actual tilt of about 2.5 degrees. That angle may not seem appreciable, but it is sufficient to tip the drum dial until it almost touches the top of the transparent case in one direction and the bottom in the other direction.

This observed tilt apparently results from insufficient or excessive balance weight to compensate for the vertical component of the Earth's magnetic field, which varies with latitude. The tilt in itself is not a major problem. However, if the drum dial is used to level the compass for inclined sights, it can cause appreciable error in the sighting direction.

To the best of my knowledge, there was never a comparable tilt problem with any of the Suunto compasses, and I never attempted to estimate the magnitude of whatever tilt was present. On several occasions I observed a slight tilt, at most a fraction of the 2.5 degrees tilt observed in the Sisteco compass.

It is unwise to attempt to make any comparisons between the two compass types on the basis of such limited data. It is only possible to say that, on the basis of a single test on a Sisteco compass, the two compass types appear to be comparable. In addition to drum dial tilt, other differences may be significant. The combined Sisteco is about twice the size of either Suunto clinometer or compass. Unlike the two separate instruments, which can be carried to different locations in difficult surveying situations, the two sections are irrevocably tied together in the Sisteco. If one section fails, the entire unit must be returned to the dealer for repair. Finally, if a plastic or glass rod is affixed to the housing for inclined sights with the compass, it somewhat obstructs the sighting for the clinometer. It is advisable to consider such potential problems before purchasing the Sisteco.

The one test not carried out on these compasses was the absolute accuracy, that is, their correspondence with magnetic north when reading 000 on the dial. One reason for this omission is that I have no good sighting landmark where I reside and where I carry out these tests. Testing at a remote site would have required the expenditure of time I could not spare when many of these tests were carried out. A second reason is that there is a basic question about what constitutes a good definition of absolute accuracy. In the case of compass no. 6, if zero degrees is used as a reference

angle, the compass reading will be in error by about one degree at an angle of 180 degrees. For this specific compass, a better solution might be to select a reference such as 270 degrees where the median occurs; thus the deviation from the median would reach a maximum equal to only one half of the total excursion. As the magnetic/optical correspondence is adjusted at the factory, it is unlikely that the manufacturer pays attention to such minor details.

Figure 6 shows a hypothetical situation for a Suunto with one degree of systematic error and factory setting errors of zero, plus 0.5 degree, and minus 0.5 degree. This figure demonstrates how the systematic error and north setting errors interact to produce bias errors of plus 0.5, plus 1.0, and zero degrees. Bias error, being non-random, will persistently enter into every reading, and the entire survey will be skewed by the bias error angle. For a survey in which the entire cave is surveyed with a single compass, there should be no great problem; the only difficulty is that the north arrow position will be in error by the amount of the bias angle.

A different situation occurs when several compasses are used to survey a larger cave, particularly one, which has rather complex interconnectivity. In that case, if one or more compasses exhibit a bias error, the resulting surveys might be difficult to join correctly. I would imagine that in any cases of this type, the surveyors would attribute the difficulty to closure error and to force a closure. The problem is that no survey is necessarily more accurate than any other. One can only hope that closure correction solves the problem.

The following tabulation is a summary of compass/sighting errors and their relative magnitude:

1. **Deadband**: A relatively small error, smallest in new instruments; the magnitude should be only a few tenths of a degree. This error is truly random; because of r.m.s. addition, this error can probably be disregarded.

2. **Systematic Error**: This error is a direct function of compass angle; the total angular deviation may be as high as one degree. In a complex, circuitous cave, the error can probably be treated as a random error, but in caves with long, straight passages, the error constitutes a bias error.

3. **North Alignment Error**: A discrepancy between the compass dial reading and the optical sighting path when the instrument is pointed toward magnetic north. Any angular discrepancy here will be non-random (i.e., constant) and will be a bias error which affects every reading. In the preceding text, it has been shown how a systematic error can interact with the north alignment to increase or diminish the bias error.

4. **Sighting Error**: In my tests, performed under ideal conditions with the compass firmly mounted, the sighting errors were very small, probably on the order of 0.1 to 0.2 degree. It can be expected that under conditions encountered in the cave, the sighting error would be larger. The best condition is when the compass is firmly held against a firm surface, such as a breakdown boulder. With less solid surfaces for support, or with no support at all, the quivering of muscles and motion of chest muscles and diaphragm will contribute a significant amount of positional instability. In addition, other factors, such as the target light not being directly over the target station or the compass not being over the sighting station, would introduce error. All of these sighting errors are truly random.

5. **Inclined Target Error**: Because of the sighting method used in Suunto compasses, targets cannot be accurately sighted when they are more than a few degrees above or below a level plane. For this reason, reflective/refractive glass rods are used for sighting targets at high angles of inclination. For accurate readings, the glass rod and compass body upon which it rests should be perfectly level. The error angle is approximately proportional to the compass tilt angle times the tangent of the inclination angle. At 45 degrees, where the tangent is 1.0, the error is equal to the tilt angle. I had suggested using the position of the compass drum dial in its window as an indication of tilt. However, Roger Bartholomew has pointed out that the dials are not always balanced to be level. Also, even in the case of well- balanced dials, levelling the compass to the dial is not easy or very accurate. The resulting error is random in nature and in actual mapping situations can and does reach magnitudes as high as 5 or 6 degrees.

Although present data is insufficient, there may be a tendency for degradation in accuracy resulting from an increase in deadband error caused by rough in-cave treatment. Relevant data may possibly be obtained by re-testing the compasses after several years of usage to see what changes the wear and tear of surveying may produce.

My primary objective in writing this report was to describe the errors inherent in the Suunto compass and its use, so that users are aware of its capabilities and limitations. Obviously, one should not expect more accuracy than the compass can provide. Also, the compass should preferably be used in situations where it can perform most effectively. Ideally, the compass should be used in large, fairly level caves where inclination angles rarely exceed 10 degrees and where both backsights and foresights can be made from every station. In caves where high inclination readings require the use of a glass sighting rod, the user should be aware of the need to level the compass and should recognise the potential for error if the drum dial inside the compass is used for this purpose.

On the basis of limited data, it appears that extended usage will degrade the performance of the Suunto. Consequently, a Suunto compass owner should treat the instrument with care, being careful that it does not impact upon hard objects or fall upon a hard floor. Again, on the basis of limited data, it does not appear that the KB-20 plastic compass is an advisable investment, even for a benign cave environment, except perhaps as a training compass or for hiking.

For Suunto compass users who do not have access to facilities for testing the compass, there is a quick hand test one may carry out. Set the compass on the edge of a wooden table or other level, non-magnetic surface and let the drum dial come to rest. Then quickly rotate the compass body five to ten degrees and observe the drum dial, which should quickly rotate to a fixed position and come to rest without any apparent sluggishness or hang-up. If a target of limited angular width is available, one may sight on this target several times, alternating on-target and off-target sightings; the compass readings for the target should all be approximately the same. Rapid, non-sticky response and closely clustered readings on target will indicate that the compass is probably performing at an acceptable level.

For many years, I have maintained that the ideal cave surveying compass has not been manufactured. The internally lighted Suunto has been a step in the right direction. What I would like to see is a Suunto with the light and an internal bubble level, and a fixed or retractable external glass rod for highly inclined sights. Finally, it would be nice to have a compass that can be sighted while lying prone in a low passage with one's chin in the dirt, but perhaps that's asking too much.

Appendix

Terminology and Description: Suunto compasses utilise a small rotating drum dial rather than a pivoted needle; I have referred to this dial as a drum for convenience. The drum is not really a right circular cylinder but actually a truncated cone, with a re-entrant upper surface. The primary degree scale, that one visible through the magnifying lens at the rear of the compass, is formed upon this conical surface. The scale consists of thin lines of three lengths: short lines occur at one-half degree increments, medium length lines occur at one degree increments, and the longest lines occur at 10 degree increments. All lines appear to be parallel, though all have an imperceptible tilt, all pointing to a vertex coincident with the conical surface upon which they are inscribed, one which is some distance above the compass itself. The longest lines, those at 10-degree increments, terminate close to an associated number consisting of three digits and ranging from zero to 350 for the Suunto KB-14/360. These numbers comprise the degree scale and indicate the orientation of the compass body with respect to magnetic north; when the observer reads zero, the black cursor line on the transparent housing (through which the drum dial is read) is visually aligned toward magnetic north.

A second set of numbers, also printed in black but one-half the size of the primary numbers, occur at the top of the conical scale, directly above the larger primary numbers. On this scale, the numerical positions are 180 degrees offset from those on the larger scale, so that backsights can be directly read as if they were foresights. On this scale, the zero occurs directly above the larger 180, and the smaller 350 occurs directly above the larger 170. The difference in numeral size is distinctive, so misreadings from the presence of two scales should be minimal.

A second scale occurs on the top, re-entrant surface of the compass drum, which is visible through the transparent window on the top side of the compass housing. This scale, unmagnified, is marked in five-degree increments, with degree numbers occurring at every 30 degrees from 0 to 330. The zero on this upper scale, as indicated by a short red cursor line inscribed on the periphery of the window, occurs at magnetic north. A third, smaller scale is inscribed inside the five-degree scale on the top side of the drum. This last scale consists only of the four cardinal directions, which are abbreviated and shown in block letters: N, E, S, and W.

If one holds the compass horizontally with the transparent window up (with the observer looking down) and then rotates the compass in a clockwise direction, say from north to east, the drum will appear to rotate in the opposite direction. The sequential appearance of the numbers in the primary number sequence, indicated by the black cursor line, will, however, increase. This direction of number increase is considered to be clockwise rotation, while the opposite direction is considered to be counter-clockwise. The same concept also holds when the drum is driving toward a null position, as shown in Figure 1.

A second type of scale occurs on Suunto compasses in which the scale is marked in quadrants, with zero degrees occurring twice, at magnetic north and magnetic south, and 90 degrees occurring at magnetic east and west. I tested one compass of this type, and it appears to be functionally identical to the compasses with azimuth scales. Quadrant scales are typical on the Brunton type compasses, which were almost universally used for cave surveying in the early days of the NSS. I personally dislike the quadrant scale because of the possibility of error in reading and transcribing the compass measurement. In addition, for those surveyors who sketch to scale, the possibility of an erroneous angle plot is not a trivial problem.

Instrument Lighting Update

Wookey

Way back in CP7 I described how to make your own lighting for Suunto-style instruments. This has now been in use for 5 years of expeditions, and so I have significantly more experience of how it works, and the problems encountered. As a result I think it is time for an update on this subject.

First a recap, especially for those of you who have joined CSG since the first articles were written.

The lighting uses a surface mount LED, which is soldered onto a strip of veroboard that holds it out over the edge of the instrument's capsule. A simple switch and batteries are connected to this. The switch is mounted on the side of the instrument so it's convenient to squeeze, and the batteries can go on top, either side of the vero, for clinos, or in various other places for compasses.

The whole thing is held in place and cave-proofed with silicone sealant and a standard Suunto rubber cover. The construction is very straightforward, and once you have done one then you can make them up in an hour or so.

Each light costs about £1.50 in parts, and they are very effective. Once you have used lit instruments like this, you really miss it if you go back to 'naked' ones where you have to wave your headlamp, or a another light, around to see the dial.

So, enough of the hard sell, what do you need to know about making these? We'll start with the individual parts, then I'll describe some of the design decisions, the construction, with particular reference to problems you might encounter and lessons learnt, and finally where to get the bits.

Parts

Switch

As described in the original article there is only really one switch that is suitable. It is a surface-mount B3S series momentary action switch. These are about 4mm square with a small circular low-profile button. The legs come out of the side and if you bend them flat with needle-nose, preferably smooth-faced pliers, then the body keeps the legs away from the metal of the instrument so you don't even need any insulation. The button is sufficiently low-profile that the thickness of the rubber cover stops it being accidentally pressed. I note that there is now a new 'high force' variant of this switch available at the same price, which is otherwise identical. I haven't tried this yet, but it may well be an improvement as accidental depression of the switch in transit can happen, and these new switches should make it less likely.

LED

The LEDs come in the tiny SOT-23 package (2.85mm x 2.5mm x 1.1mm high - and that includes the legs!) there is a choice of three colours - red, yellow and green. They have a nominal current of 10mA, but are typically run at significantly higher current than this, due the absence of a current-limiting resistor in the design. You could add one if you like, but I've found it works fine like this and don't see the need, although it would be good electronic engineering practice, and would increase the life of the cells. Maybe I should try it sometime…

Run from a pair of Silver Oxide cells (nominal voltage 3.1V, i.e. 1.55V each) the HE red LED draws 35mA - i.e. 3.5 times its nominal rating. This gives a very bright, well-illuminated display. The actual battery voltage for this test was 2.7V, dropping to 2.4V when the light was on. At the same voltage and current, the yellow LED is significantly less bright but still gives a very-well-illuminated display. I have taken to using red for compasses and yellow for clinos, but both work very well. You could afford to current-limit the red LEDs to about 20mA and still get very good lighting.

By the time the cells get down to 1.5V the LED draws 4mA and is relatively dingy. However this still gives much better lighting than the Suunto electric light. It is dingier, but much better directed. It is also still much brighter than the tritium illumination. This suggests that you can get away with running the lights of a single 1.5V cell, although you may find that you won't get full capacity out of the cell as once it has run down a bit and its voltage dropped to around 1.35V it may not light the LED sufficiently, if at all.

Batteries

There are a number of options here. I have used 3V lithium coin cells (the sort typically found in watches and calculators), and 1.5V silver oxide cells. The lithium cells are thin but large (e.g. CR2016 is 1.6mm thick, 20mm diameter). The button cells are small but fat (5.6mm thick, 12mm diameter). There are plenty of other options that would work.

The choice of cell chemistries is:

Chemistry	Nominal Voltage	Capacity for 11.6 x 5.4mm size	Cost
Silver Oxide:	1.55 V/cell	165 mAh	79p x 2
Alkaline:	1.5 V/cell	110 mAh	15p x2
Lithium:	3 V/cell	~90 mAh	90p
Zinc-Air:	1.4 V/cell	520 mAh	48p x2

You used to be able to get mercury cells but these don't seem to be available any longer. Note that the lithium cells are not available in this size so the equivalent capacity is estimated by volume. Zinc-air would appear from this table to be optimal, but they have one major disadvantage. They need air to operate, and once 'opened' have a relatively short life. This means you can't completely waterproof them, and if you leave the instrument sat around for a few months, chances are the batteries will be flat - so not really much use. However for an expedition, it might well be worth fitting these to guarantee the lights lasting for a couple of months of intensive use.

The silver oxide cells have the next best capacity, and I have been using them almost exclusively, mostly because I bought quite a few at 25p each. These seem to have been discontinued (GPI RM675 - snap them up if you see them!). And what remains is relatively expensive.

Alkaline cells have not long been available in button-cell form, but they are very cheap, and offer reasonable capacity. I haven't tried them yet, but will do very soon, as I need some new cells.

Lithium cells are neither cheap nor high capacity, and for compasses at least, it is impossible to mount them satisfactorily. For clinos a single CR1620 cell gives a very slim-line solution, so if size is a significant consideration, then that would perhaps be a reason for choosing these cells, otherwise the others are better.

A word on nomenclature: button cells have a wide range of names and numbers. The size I have been using (the largest commonly available) is 11.6mm diameter by 5.4mm high. This is called V357, RM675, SR44, LR44, A76, and several other less-common designations. The letters at the front sometimes indicate battery chemistry (e.g. LR and A indicate alkaline, SR and RM indicate Silver Oxide).

There are plenty of smaller sizes available which might be useful - e.g. the 11.6mm diameter gives options of 2.1, 3.1 and 4.2mm thick, at about 25%, 42%, and 72% capacity of the 5.4mm thick cell respectively.

These cells have bright/stainless steel cases, and thus are all magnetic. The only non-magnetic cell I have come across is the aluminium-bodied 3V lithium cell used by Suunto in their electric lights. These are made by 'National' and have the number BR425. Suunto charge £7.00 each for them! I have never seen them for sale elsewhere, although I have been told it is possible to buy them for about $2.00. If a UK source of these could be found then these cells might well be worth considering as they are small and simplify the problems of cell mounting on compasses (see 'Battery Mounting', below).

Design Criteria

Battery Capacity

A pair of 165mAh silver oxide cells will nominally give at least 16 hours of light with the 10mA LED, however as the LED actually draws 35mA in this circuit, you will actually get about 5 hours. That doesn't sound like much, but it's actually a lot of sighting-time. Some of the first lights I made 4 years ago have only just gone flat, with 4 weeks intensive use on expedition every year.

A typical sighting is generally less than 10 seconds, although awkward ones, such as steep compass legs can be much longer. This works out at about 1600 sightings before the batteries go flat. That should be plenty for most people. Flat batteries have generally occurred where the switch hole has become completely bunged up with mud so the switch is jammed on. There have also been a couple of failures due to short circuits due to poor construction techniques (see soldering cells).

In practice I have found that simply changing the dingy ones after expo each year works very well, and I may try using some regulation (for better efficiency), or smaller cells (to make the instruments less bulky) in the light of this.

Battery mounting

For clinos this is no problem. You can put them wherever you like, and I have found that on top of the instrument, in the space between the sighting lens and the capsule, one either side of the LED vero, is best (see Figure 2).

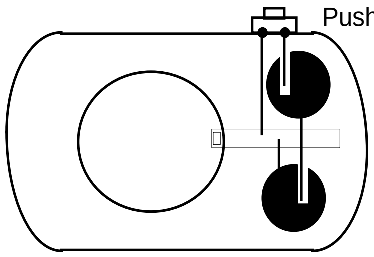

Figure 2- Battery mounting & wiring for clinos

For compasses, the problem is much harder and there is no perfect answer. You can't put the cells on top, as with the clino, as their steel cases will affect the compass. Tests have shown that they really don't have to be very far away for there to be no deflection of the compass. Mounting them on the back of the instrument, either side of the eyepiece, is sufficient. The only problem with this, is that there isn't much room here, and you end up with a very deep eyehole as the cells push the rubber boot back 5-6mm. This narrows the field of view somewhat, and most importantly makes it difficult to get crap out of the hole or clean the lens, as your finger won't reach anymore.

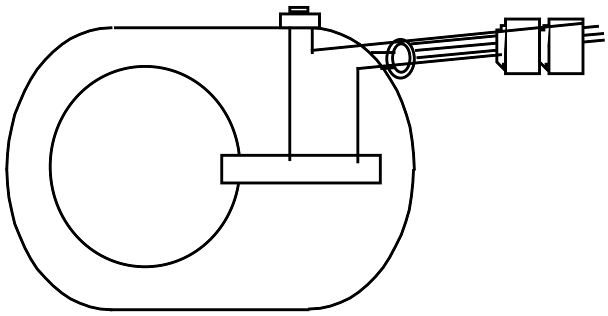

Figure 3- Battery mounting & wiring for compasses

Given these disadvantages I tried mounting the cells on the lanyard, about 5cm from the instrument (see Figure 3). This has the advantage of being compact, and definitely out of range of any magnetic interference. The obvious disadvantage is that it doesn't seem very robust. However, in practice I have no problems with this arrangement despite giving it to expo cavers two years running, so this is now my favoured configuration.

Construction

It is obviously important that the light stays working, otherwise its useless (maybe even worse than useless if you were depending on it and have left your normal illuminator at home so you have to faff about with your helmet light, slowing down the whole surveying process). Most of the reliability of electrics is in constructing it right. After building quite a few of these I think I have come across most of the possible pitfalls, so I hope I can steer you away from making the same mistakes.

When you cut the hole for the switch in the rubber cover it is important to get it just the right size. It needs to be big enough to fit over the switch without rubbing on the plunger, as that would impede its motion and perhaps make it stick on. However, it is also important that its not too big, as then it tends to slip off the square base of the switch, leaving the plunger exposed to the caving elements, which means it will get pushed on whilst moving around, prematurely flattening the battery.

When you cut the hole you need to allow a bit for the fact that the rubber boot is somewhat stretched over the switch and batteries so the hole will be a bit bigger in situ than when you cut it. It is also difficult to cut a genuinely round hole. A suitable punch cutter (3mm) would be good, but I just use a pair of Swiss army knife scissors, which works acceptably well.

Soldering the LED to the veroboard is fiddly but straightforward. Cut a strip of vero with two tracks on it, about 9 holes (2.5cm) long. Solder the LED on this right at one end. The LED has three legs, two of which are connected together, so you have to solder it on slightly offset, with the centre and left-hand legs on one track, the right-hand on the other, as shown in Figure 4.

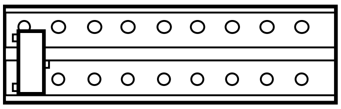

Figure 4 - Surface mount LED mounted offset on strip of veroboard

Next attach two wires towards the other end of this vero strip. Remember this will be mounted upside down so keep the protruding ends of wire short, and preferably file them and the solder smooth. This stops the pointy bits cutting through the insulation to the aluminium below and shorting.

To insulate the strip from the instrument body you can use insulation tape, gaffer tape or bike inner tube. The latter is strongest and definitely won't be punctured, but is also quite thick. I prefer to use insulation tape, and be careful about rough or pointy soldering. The same considerations apply to the cells, which must also be insulated from the instrument body in the same way if mounted on the body. For top-mounting it is easiest to put a couple of strips of insulation tape on to cover the whole area where LED and cells are to go.

The wire from the 'plus' side will go to the switch, the 'minus' wire will go to the 'minus' side of the first cell. You will also need a wire from the plus side of the first cell to the minus side of the second, and one from the plus side of the second cell to the switch. You will need to think for a moment about exactly what goes where, and which way up to get these wires the right lengths and properly connected up. In theory, wiring up the LED the wrong way round can blow it up, but in practice it doesn't seem to mind a bit of reverse voltage.

Mount the switch on the side of the instrument where you hold it. It doesn't need insulating from the instrument body, although it might be a good idea to put a bit of insulation tape on 'just in case'. You do need to carefully straighten the legs of the switch so that come out parallel to the instrument body. This stops them touching the body. The switch has four legs. The legs opposite each other are connected together, so you simply ignore the pair on one side, and solder to the pair on the other side.

Make the wires slightly longer than is necessary. It's easy to fold a bit of extra wire in, and it will make maintenance easier, but if it doesn't quite reach then you'll have to solder it on again.

Note that for compasses you will need to thread the wires through the same hole that the lanyard ring goes through *before* you solder them to the cells. Make sure you use flexible wire that's not too poxy for this bit, as it will take a fair amount of wear and tear.

Soldering cells

This is the trickiest bit. The problem is that there isn't enough room to use cell holders and most of the useful cells don't come with tabs so you have to solder directly to the cells themselves. If this is not done properly then all the insides of the cell boil out and either its life is significantly shortened, or it may be knackered completely. So some care is required.

Two problems combine to make it difficult to solder to these cells. 1) they are very small and so it doesn't take much heat input to get them very hot, and 2) the stainless steel cases are not easy to tin.

I have tried various techniques, and by far the best is to get hold of some phosphoric acid. You only need a tiny amount (1ml or so) to make a lot of good solder joints. Unfortunately I don't know a good source for this - I got mine from a friend's lab. Try pestering a chemist. A tiny dab of this on the scraped surface of the steel will allow a quick dab of the iron to tin the cell.

An alternative I tried was conductive epoxy glue. This stuff has the major disadvantage of being extremely expensive, presumably because it is full of silver. A couple of tiny tubes (14g) costs £19.20. However it allows entirely cold conductive joints to be made so I thought it was worth a try. It does work, and can be very good, but there are some ifs and buts. You need to be very careful to mix it thoroughly and get the proportions right, which is difficult as you use it in such tiny quantities. If you don't then it doesn't set properly and you just get conductive goop everywhere instead of a proper joint. Whilst waiting for it to set you need to be very careful not to move the wire around when doing the 'minus' side of the case, as it is very easy to get a bit of glue spread across the case seal, thus shorting the cell. It will, of course, go flat if left like this for any time. The other disadvantage is that it takes a long time to make four joins of wire to cells if you have to wait for an hour for the epoxy to set on each one; several evenings end up being required, especially as I found at least one would fail to set properly. When it works it is very strong, and it is particularly good for gluing a pair of cells on top of each other for lanyard mounting, but apart from this I would say spend the money on phosphoric acid instead.

Of course it is quite possible to solder the cells up without anything more than a soldering iron and some solder. You just have to be quick and sure. (A bit of practice will help if you don't do much soldering). Clean and scratch the cell surface well with a knife blade, then stick the iron on with the solder. The moment it melts remove the iron and leave the cell to cool. It may take half an hour to get back to 'cool'. Once it has done so, you can tin the wire end and then solder it on as quickly as possible.

When soldering to the 'minus' plate take care that the bare end of wire is short enough that it will not short across the cell seal when the cell is pressed into place on top of the wire. Also file down any protruding solder spikes.

Assembly

Once you have done all the soldering (it's not as hard as all the above probably makes it sound) you will have a little springy collection of bits. Play with it a bit, and satisfy yourself that it does indeed light the instrument nicely. You can determine the optimum position for the LED at this point.

For top-mounted cells I find it is best to mount the cells plus-side down. This reduces the pressure on the wire where it crosses from the 'minus' plate to the 'plus' case. The boot pushes the cells into place quite hard and this can break the insulation if the wire is squashed between the cell and the instrument body. For the lowest-possible profile you could solder to the sides of the case for the 'plus' connection. I haven't tried this, but it might be quite smart, if a bit fiddly.

You now have the amusing game of gunging this into place with silicone sealant, and then pulling the rubber boot over the top. In short this is a very messy activity. If you are not doing very wet caving, then it is a lot easier to assemble the parts 'dry' and pull the boot over, then squirt silicone in under the boot. This doesn't completely seal things in, but it makes minimal mess and does hold everything in place. Be sure to get the switch properly positioned under the hole in the rubber boot, and that the light is still working before you leave it to set. Also ensure the LED is correctly positioned over the edge of the dial. For a completely sealed set-up you need to gunge some sealant on first, then pull the boot on (everything slides everywhere, and it's great fun ☺), before completing the job once it is assembled and positioned.

Don't forget to put silicone into the space between the LED and the capsule, otherwise it fills up with dirt and you can't get your finger in to remove it. Being clear. It doesn't stop you using an external light should the internal die for some reason.

One thing to beware of is that the lanyard ring usually becomes trapped under the boot when assembling it, and especially if you are trying to squirt in silicone and put it all together at the same time, this is easily forgotten. It is easiest to simply unscrew and remove the lanyard ring and lanyard before assembling the light, then put it back in later.

For compasses getting the boot and silicone on is much easier than for clinos as there are no cells so there is less stretch in the boot. You need to attach the cells and wire to the lanyard. I have used gaffer tape for this as it is cheap and effective. Other forms of tape would also work. You could even use self-amalgamating to make it totally waterproof.

Maintenance

Eventually your cells will go flat and you'll have to replace them. This is very easy in principle, but the silicone makes it a bit more interesting. It is generally not possible to solder a new cell on in-situ, and you will need to pull out a bit of extra wire or cut back the silicone to get a bit of wire to work with. Remember which way round the cells are so you can put the new ones back in the right way round.

I have also had to replace a couple of switches that had simply died. This is very straightforward.

Suppliers

If you want to buy these bits then one source is Farnell:

B3S switch: 177-807 52p each
B3S (high force switch) 959-728, also 52p
LEDs: all £3.60 for 10
Red: 515-656, Yellow: 515-668, Green: 515-670

Batteries are very expensive in the high street, and somewhat expensive from Farnell. CPC are my favoured suppliers.

Alkaline: all 10 for £1.53
LR44, A76 (11.6x5.4mm) 110mAh: BT00268
LR43, 186 (11.6x4.2mm) 70mAh: BT00272
LR42, 189 (11.6x3.1mm) 44mAh: BT00273

Silver Oxide:
SR44, 357 (11.6x5.4mm) 165mAh: BT00042 79p
SR43, 386 (11.6x4.2mm) 120mAh: BT00049 67p
SR54, 390 (11.6x3.1mm) 70mAh: BTGP-390 47p

Kit and fitting service available

I can supply kits of parts for this. A kit includes: one switch, 2 cells, an LED, a bit of vero and instructions (basically a copy of this article) for £2 including VAT and postage. If you need a rubber boot too, then add £5.60.

If it all sounds too difficult and you want one ready-assembled then I can supply a wired-together light for you to fit for £10 (£15 if you need a rubber boot) (you need to say if it is for compass or clino). Alternatively send me your instrument and I will fit the whole thing for £15 (£20 if you need a rubber boot).

Radiolocation Errors Arising from a Tilted Loop

David Gibson

***An** analysis of the errors in depth and Ground Zero that arise if an underground transmitter loop is not precisely levelled for radiolocation.*

Introduction

In CREG journal 28 (Gibson, 1997) I quoted the “thirds” rule for radiolocation, which describes how an error in Ground Zero can occur if the radiolocation transmitter loop is tilted. I invited people to send in a proof of this rule. As I reported later, the only entrant, and therefore the prize-winner, was Olly Betts.

Not only Ground Zero, but depth measurement is also affected by a tilted loop, as I will explain in this article, which also contains a description and proof of the “thirds” rule.

The “Thirds” Rule

In my articles on the accuracy of radiolocation I discussed the error that was introduced by the underground antenna not being horizontal. Figure 1 shows the field lines from a loop that is tilted by an angle β (which is exaggerated in the diagram). The axis of the loop, *QX*, when projected as far as the surface, will be displaced from ground-zero (*O*) by a small amount. For example, if β is 5º and *D* = 50m then the displacement is around 4.4m.

Because of the curved nature of the field lines, the line that is vertical as it leaves the ground will be displaced by a smaller amount than the axial field line. This can easily be seen from Figure 1 where a curved field line leaves the ground vertically at *W*. Since it is this vertical field line which is used to determine ground-zero, the error in the measurement of ground-zero will not be as great as *OX*. In fact, for small values of β is it exactly a third as much. In other words, $OW = {}^{1}/_{3}OX$ – ***the apparent Ground Zero is a third of the axial displacement from true Ground Zero.***

As far as I know, this had not been published as a proven fact prior to my article on radiolocation errors (Gibson, 1996). I have

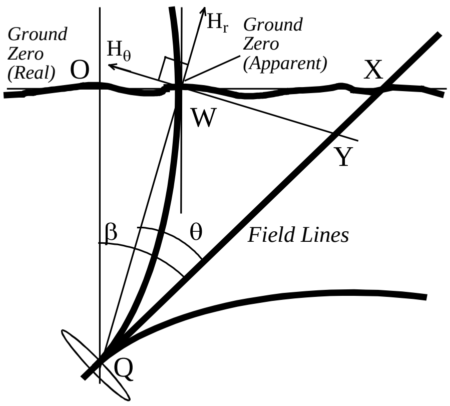

Figure 1 – field lines from a tilted loop.
The apparent ground-zero (W) is 1/3 the displacement (X) from true ground-zero (O)

referred to it as the “thirds” rule. Brian Pease brought it to my attention as an observation he had made but not proved.

Proof [1]

The radial (*r*) and transverse (θ) fields from a quasi-static magnetic dipole are known to be

$$H_r = \boldsymbol{M}\frac{\cos\theta}{2\pi r^3}, \quad H_\theta = \boldsymbol{M}\frac{\sin\theta}{4\pi r^3} \qquad (1)$$

where θ is measured from the axis of the loop, *r* is the distance from the loop and ***M*** is the dipole moment.

The radial field at point *W* is in the direction *QW* and the transverse field is at right angles to this, as shown in Figure 1. The angle between the radial field and vertical is β-θ so the overall vertical field is

$$H_v = H_r \cos(\beta-\theta) + H_\theta \sin(\beta-\theta) \qquad (2)$$

and the horizontal field is

$$H_h = H_r \sin(\beta-\theta) - H_\theta \cos(\beta-\theta) \qquad (3)$$

The condition we require is that the field is entirely vertical; i.e. $H_h = 0$ so from (3)

$$\tan(\beta-\theta) = \frac{H_\theta}{H_r} \qquad (4)$$

and from (1),

$$\tan(\beta-\theta) = \tfrac{1}{2}\tan\theta\,, \qquad (5)$$

If angles are small, then tan*a* ≈ *a*. This is correct to 1% if $a <$ 0.17rad, or 9.7°. We can therefore write

$$\beta-\theta \approx \tfrac{1}{2}\theta \quad \Rightarrow \quad \beta-\theta \approx \tfrac{1}{3}\beta \quad (6)$$

Using the approximation for small tangents it is now trivial to show that this implies that distance *OW* is a third of the distance *OX* – which is the result we are looking for.

It is useful to express this error in Ground Zero estimation as a fraction of the loop depth below the surface. Referring to figure 2 for the definition of *x* and *d*,

$$\frac{\textit{error in } x}{d} \approx \tfrac{1}{3}\beta, \quad \beta < 0.2\text{rad} \qquad (7)$$

where β is measured in radians. With β in degrees we would have

$$\frac{\textit{error in } x}{d} \approx \tfrac{1}{172}\beta^\circ, \quad \beta^\circ < 10^\circ \qquad (8)$$

Radiolocation formula

This is a suitable point to explain the derivation of the standard radiolocation formula, which has been quoted by many people.

1 My version of this proof differs slightly from Olly Betts’, in that it is based on a more fundamental expression of the field lines. Olly based his proof on an intermediate result (quoted in equation 11), which makes it a bit more complicated to write down

Let α be the angle that the field line makes with the ground, x be the distance to ground-zero and d be the transmitter depth below the surface (see Figure 2 below).

If the loop axis is vertical, so that β=0 then we can uses similar expressions to those in the previous section (allowing for a slight change in geometry) to write

$$\begin{aligned}\tan\alpha &= \frac{H_v}{H_h} \\ &= \frac{H_r\cos\theta - H_\theta\sin\theta}{H_r\sin\theta + H_\theta\cos\theta} \qquad (9) \\ &= \frac{2\cos^2\theta - \sin^2\theta}{3\sin\theta\cos\theta}\end{aligned}$$

Dividing throughout by $\cos^2\theta$ gives

$$\begin{aligned}\tan\alpha &= \frac{2-\tan^2\theta}{3\tan\theta} \qquad (10) \\ \Rightarrow &\tan^2\theta + 3\tan\alpha\tan\theta - 2 = 0\end{aligned}$$

which is a quadratic in $\tan\theta$ that we can solve to give

$$\tan\theta = \frac{\sqrt{\left(8+9\tan^2\alpha\right)} - 3\tan\alpha}{2} \qquad (11)$$

in which we choose the correct sign of the square root, to give a sensible answer, and we note that

$$\tan\theta = \frac{x}{d} \qquad (12)$$

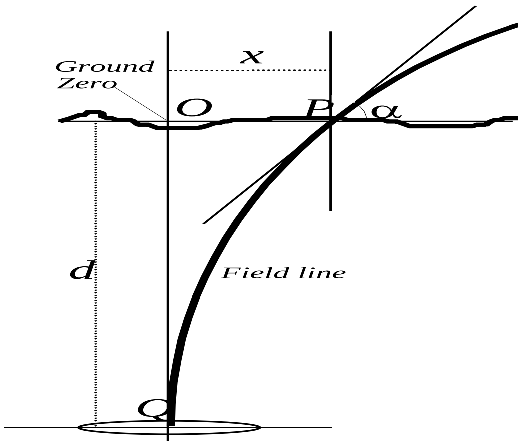

Figure 2 – depth determination with a horizontal loop

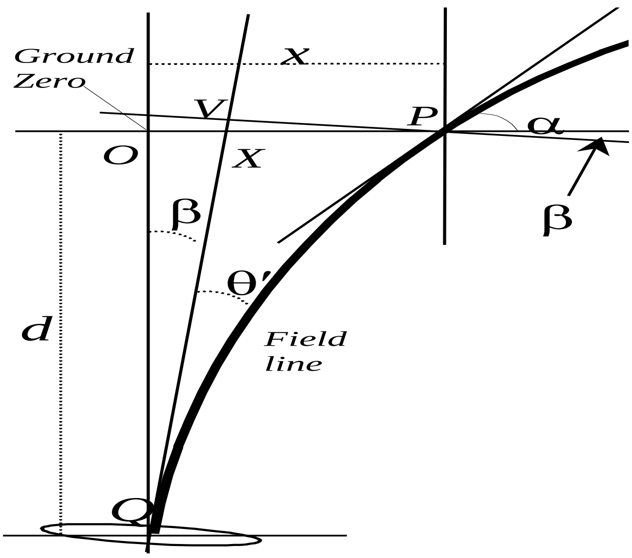

Figure 3 – depth determination with a tilted loop

Depth error due to tilted loop

We have already seen that a tilted transmitter loop leads to an error in Ground Zero. It is now interesting to investigate the effect a tilted loop has on this depth estimation. The algebra is somewhat tricky, so it is best to begin by giving an example.

Example

Suppose the loop is 50m underground and it is tilted by 5° (0.087rad). What do we actually measure?

The 'thirds' rule, as stated in equation 7, tells us that Ground Zero will be in error by 2.9% of the loop depth, which is 1.45m.

Now suppose we do the depth measurement in the usual way, by finding the distance at which the field angle is 45°, for which we know (from equation 11) that $x/d \approx 0.562$. If the loop was absolutely level then we would expect to measure x = 28.1m, and so we would obtain the depth as 0.562 ÷ 28.1 = 50m. When we measure the field line to be 45° from horizontal we will, because the loop is tilted by 5°, be looking the 'wrong' field line. We will not know this, of course, because we will be assuming that the loop is horizontal.

Within our tilted frame of reference the angle we should, in fact, be putting into equation 11 is $\alpha+\beta$, i.e. 50°. This gives a value for $\tan\theta'$ of 0.492, where the prime denotes that θ was derived from the tilted loop. $\tan\theta'$ is ***not*** now x/d because the field lines are tilted. Instead, it is VP/QV as shown in Figure 3. (For clarity, Figure 3 does not show W, the apparent Ground Zero).

We noted earlier that for small a, $\tan a \approx a$. Similarly $\cos a \approx 1$ so we can say that $QX \approx OQ$, $VP \approx XP$, and we can go on to derive

$$\begin{aligned}x &\approx OX + XP \\ &\approx d\left(\beta + \tan\theta'\right)\end{aligned} \qquad (13)$$

In our example, d = 50m, β = 0.087rad and we have just derived $\tan\theta'$ = 0.492 so we know from this equation that x/d = 0.579 and x must be 29.0m.

At this point you may be getting a little lost – what we have shown is that the *real* value of x is 29.0m. However, because Ground Zero is displaced from O by 1.45m we will actually measure it as 29.0 – 1.45 = 27.5m. Because this is in error it will affect our derivation of the depth, but the depth error is further complicated by the error in α. When we measure the field line angle, we assume that the loop is completely level and so we assume (with α = 45°) that x'/d' = 0.562. Using the measured value for x' (to the displaced Ground Zero) of 27.5m this gives an apparent depth d' of 48.9m.

The error in GZ causes us to underestimate d but, due to the tilt, x' is larger than we would expect. This compensates to some extent, so the error is less than it would be.

Formula

We can encompass the above example in the following set of formulas. The apparent depth d' is given in terms of the angle of the field line α that we measure at a distance x' from the apparent GZ.

$$\tan\theta' = \frac{\sqrt{\left(8+9\tan^2(\alpha+\beta)\right)} - 3\tan(\alpha+\beta)}{2} \qquad (14)$$

(in the example, α=45°, β=5° and so $\tan\theta'$=0.492). We have seen that

$$\frac{x}{d} = \beta + \tan\theta' \qquad (15)$$

(in the example, with β=0.087rad this was 0.579). But we do not know x, mistaking x' for x, and working out the depth with

$$\frac{x'}{d'} = \tan\theta \qquad (16)$$

(in the example this was 0.562) In addition, we know the error in x to be

$$x - x' = \tfrac{1}{3} d\beta \qquad (17)$$

(In the example, with d = 50m this was 1.45m), and so, from these three equations, we can express the ***error in depth determination*** as

$$\frac{d' - d}{d} = \frac{\frac{2}{3}\beta + \tan\theta'}{\tan\theta} - 1 \qquad (18)$$

Verifying this for the example given earlier, the fractional depth error is

$$\frac{\frac{2}{3} \times 0.087 + 0.492}{0.562} - 1 = -2.1\% \qquad (19)$$

which, with a depth of 50m, is 1.1m, as we obtained before.

Comment

We would not normally operate with 5° of tilt but, if we did, the errors in GZ and depth would still only be 2.9% and 2.1% which, for a depth of 50m, are 1.45m and 1.1m. Whether you consider this to be serious, or just an academic observation probably depends on your circumstances. The errors will be proportionately smaller for shallower depths or smaller amounts of tilt.

It is worth noting that if we do the measurements with $\alpha = 18°$ then $\tan\theta = 1$ and (for β=5°) $\tan\theta' = 0.914$; the depth error increases only slightly, to 2.8%. On the other hand, a shallow angle for α might lead to other inaccuracies.

Any further insight into the depth error is difficult because it is tedious to try to simplify the $\tan\theta'/\tan\theta$ expression. Since β is small we can derive

$$\tan(\alpha + \beta) \approx \beta \sec^2 \alpha + \tan\alpha \quad (20)$$

which, if $\alpha = 45°$, gives

$$\begin{aligned} \tan(45° + \beta) &\approx 2\beta + 1 \\ \tan^2(45° + \beta) &\approx 4\beta + 1 \end{aligned} \qquad (21)$$

which is not particularly inspiring, and so I'll leave the details for a future exercise.

One final point worth noting: Although stated in the past that a tilted loop implies that the null might not be as deep as it could be, this is probably a minor concern, given the effect of secondary fields on a good null.

Summary & Conclusions

We have proved a 'thirds' rule that says that the displacement of Ground Zero is a third of the axial displacement on the surface, due to a buried horizontal transmitting loop with a slight tilt. Another way of expressing this is that the ratio of Ground Zero error to true depth is $^1/_3\beta$ where β is the tilt in radians.

We have shown that this tilt gives rise to an error in depth determination when the method of measuring the field line angle is used. The error is complicated to express, but is given by equation 18 together with 11 and 14. Under normal circumstances this error seems to be of a similar magnitude (as a fraction of true depth) to the GZ error.

These results may not be of earth-shattering importance, as they only become significant for large depths; and it is usually easy to level a loop to much better than 5°. Other sources of error are likely to be more significant, such as measurement accuracy and effects due to secondary fields, as discussed in Gibson, 1996. It is, however, satisfying to be able to prove an observation made by practical experimenters, and to verify that loop tilt is not often likely to be a serious problem.

In a future article I will explore an important new method of depth determination utilising field gradient measurements.

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