INTERMAGNET and its standards

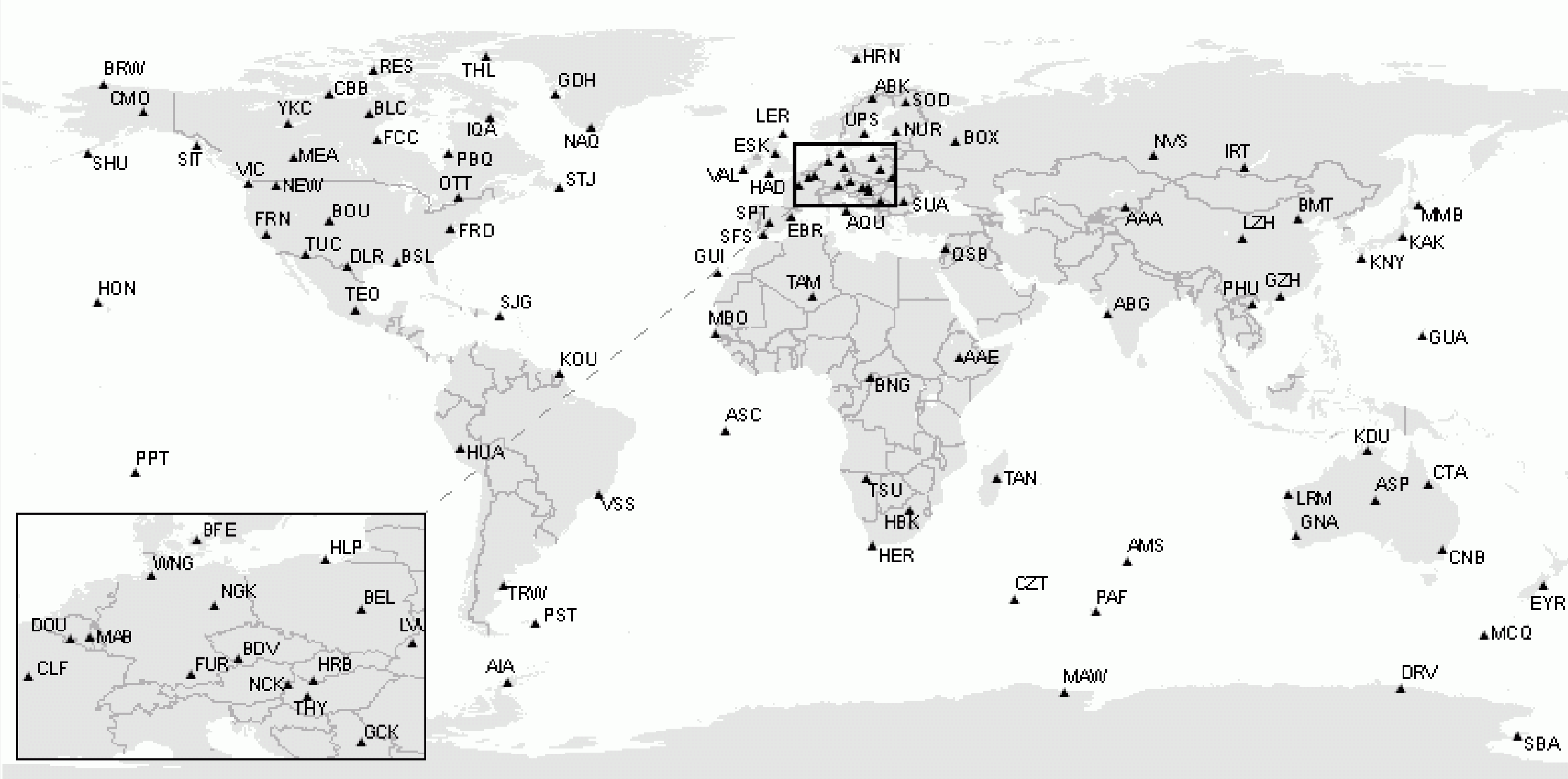
- The INTERMAGNET programme exists:
  - –to establish a global network of cooperating digital magnetic observatories
  - –to adopt modern standard specifications for measuring and recording equipment
  - –to facilitate data exchanges and the production of geomagnetic products in close to real time.

INTERMAGNET and its standards

- **Council**
- The Executive Council establishes policy for INTERMAGNET, deals with questions of international participation and data exchange and communicates with national agencies and international scientific and funding agencies. It is assisted and advised by the Operations Committee.

- **Operations Committee**
- The Committee is also responsible for establishing and maintaining standards and formats for the global exchange of data under the INTERMAGNET programme, for designing and publishing the INTERMAGNET Technical Manual and producing the annual CD-ROM.

INTERMAGNET and its standards 107 IMO's



Absolute Procedures for Observatory and Repeat Magnetic Measurements

ON OBSERVATÓRIO NACIONAL

INTERMAGNET and its standards

- Definitive data: accuracy +-5 nT

- Vector magnetometer
  - Resolution 0.1 nT
  - Dynamic range 2000 – 6000 nT
  - Band pass DC to 0.1 Hz
  - Sampling rate: 1 Hz
  - Thermal stability: 0.25 nT/C
  - Long Term stability: 5 nT/year

- Scalar magnetometer
  - Resolution: 0.1 nT
  - Accuracy 1 nT
  - Sampling rate: 30 sec

INTERMAGNET and its standards

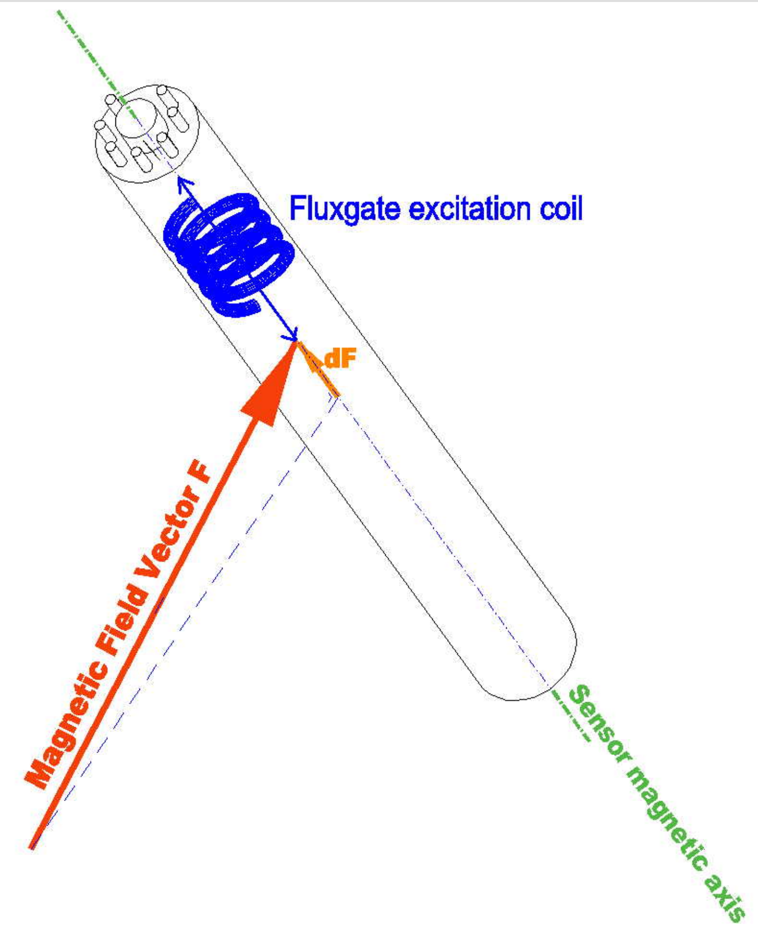
- Absolute measurements
  - From daily to several times a year dependent on variometer characteristics, stability of piers.
  - The quality fo observations judged from baseline plots.

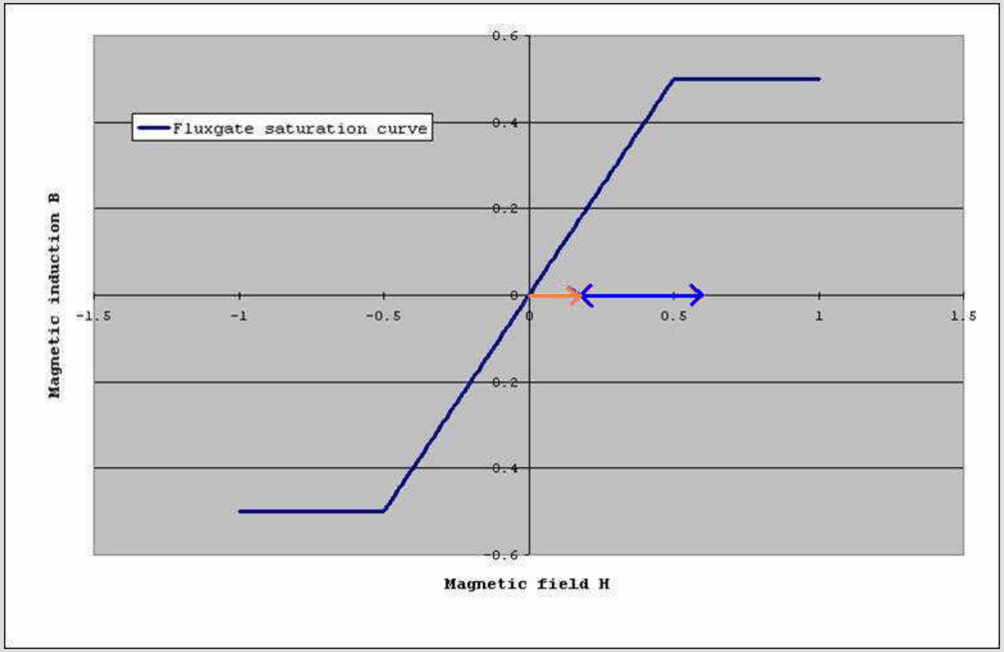
- Filtering:
  - 1-minute data are calculated from higher sample rate data (1-5 sec) using digital filter centred on the minute.
- Timing
  - Datalogger: 5 sec/month
  - Satellite transmission: +-1 to +- 1.5 sec
- Transmission
  - With 72 hours by Internet or satellite
- Definitive data
  - Data and baseline values must be submitted for annual CD-ROM

Selected DIflux Topics

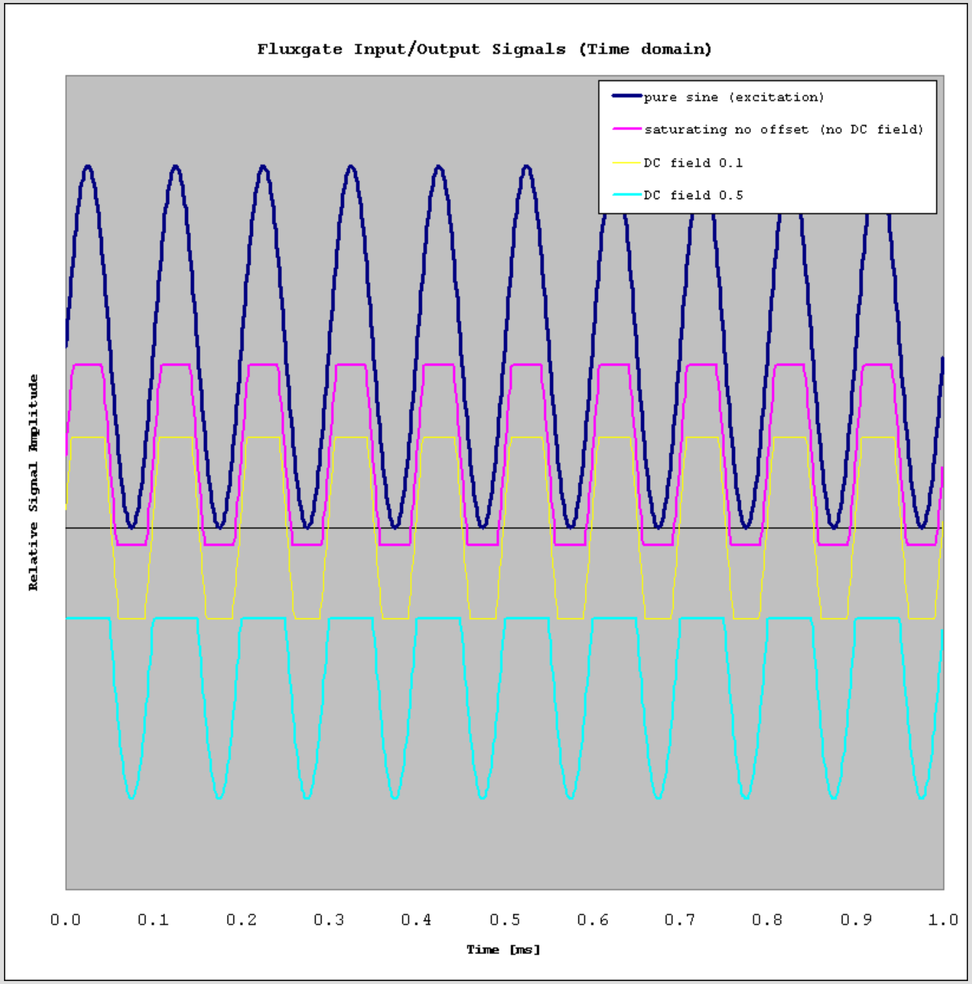
- *Fluxgate electronics basics*
- *Analysing DIflux measurements : Azimuth, Site and magnetisation errors*
- *DIflux magnetic hygiene check*
- *Passing the 1 minute time barrier*
- *Specs of commercial and other available devices*
- *Troubleshooting of the ZEISS 010/15/20*
- *Optics cleaning*

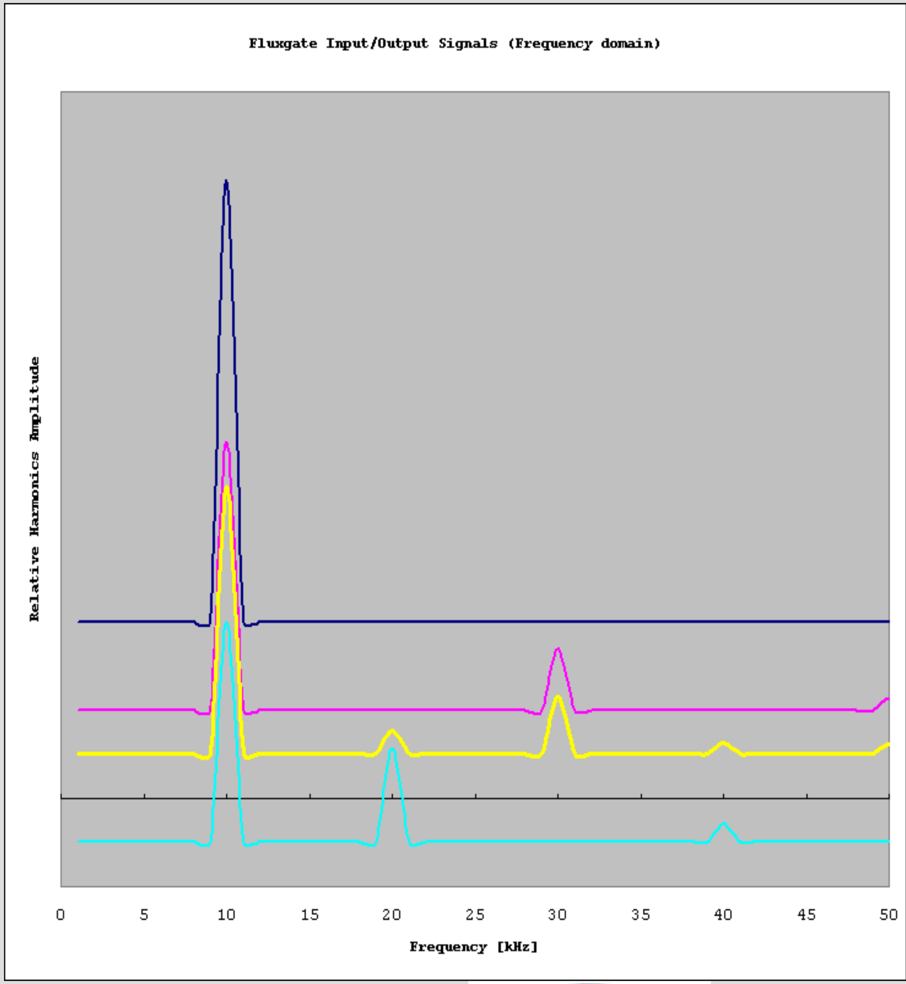
Selected DIflux Topics: Fluxgate electronics basics





Selected DIflux Topics: Fluxgate electronics basics





Absolute Procedures for Observatory and Repeat Magnetic Measurements

ON OBSERVATÓRIO NACIONAL

Selected DIflux Topics

Analysing DIflux measurements : Azimuth, Site and magnetisation errors)

- The readings of the four D-positions gives:
  - Mean Declination $D = (A1 + A2 + A3 + A4) /4 - \pi$ rad
  - Magnetisation error $S = (A1 - A2 + A3 - A4) /4 *H$ rad
  - Elevation or Site error $\varepsilon = (A1 - A2 - A3 + A4 +- 2\pi) /4*H*/Z$ rad
  - Azimuth error $\delta = (-A1 - A2 + A3 + A4) /4$ rad

- When you plot the collimation errors it is often convenient to convert them to equivalent nT so that S, ε and δ can be compared:
  - Magnetisation error $S = (A1 - A2 + A3 - A4) /4 *H$ nT
  - Elevation or Site error $Z*\varepsilon = (A1 - A2 - A3 + A4 +- 2\pi) /4*H$ nT
  - Azimuth error $H*\delta = (-A1 - A2 + A3 + A4) /4*H$ nT
- Please be careful using these formulas as the sequence of positions 1,2,3,4 may be different that the one your are using.

Selected DIflux Topics :

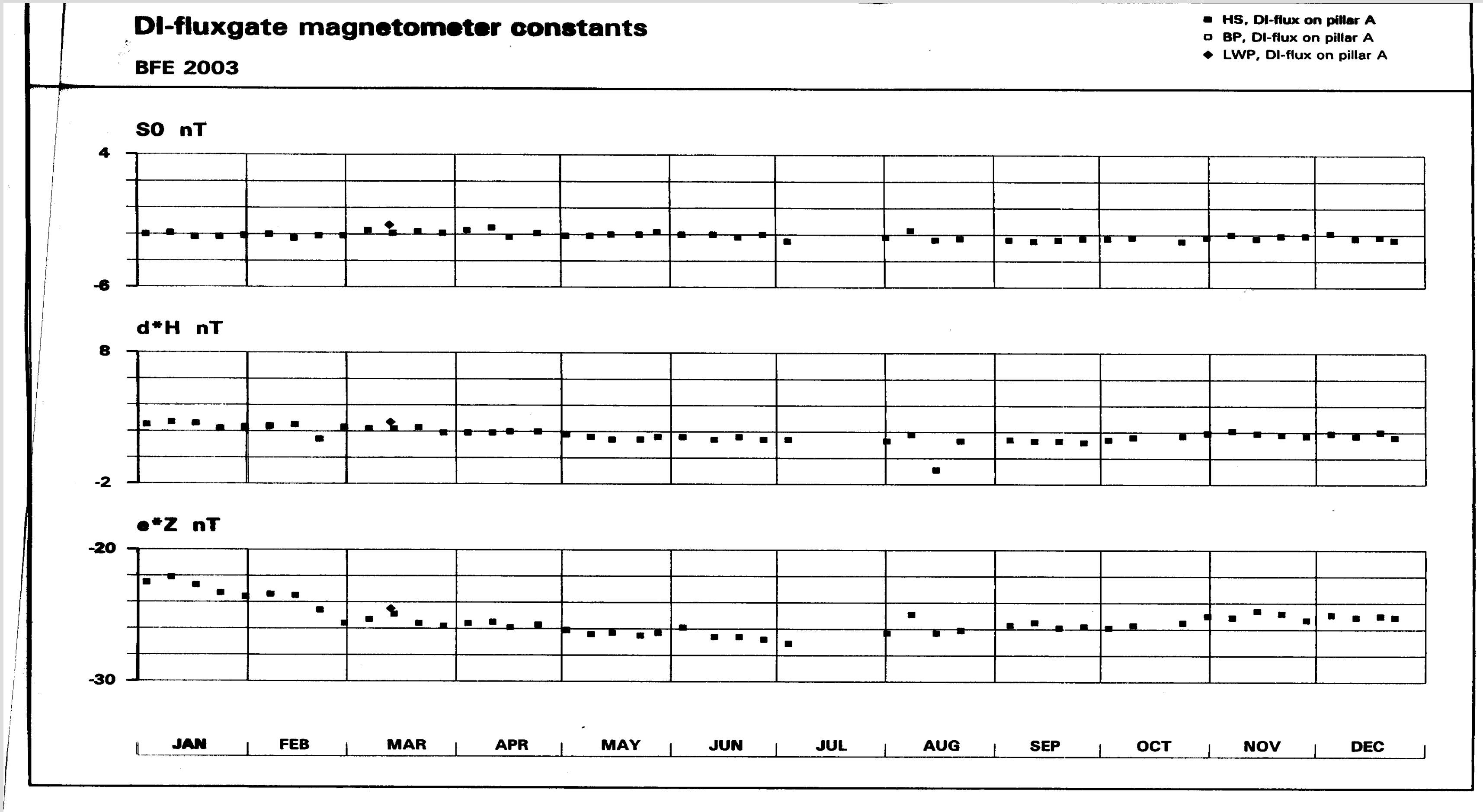
Analysing DIflux measurements : Azimuth, Site and magnetisation errors (Ole)

- Similar formulas for the four I-positions gives:
  - The inclination in the two UP positions (I_H)
  - The inclination in the two DOWN positions (I_L)
  - Magnetisation error S
  - Elevation or site error ε

- All three instrument errors are eliminated using the four positions for D and I

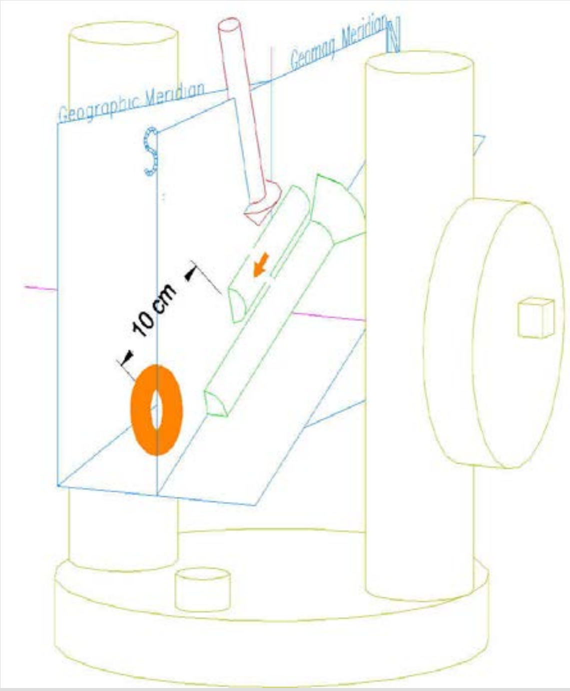
- The size of the three instrument errors should be kept small to make the measurements faster, but constant values of 100 nT will not incluence the accuracy of the measurements.

Azimuth, Site and magnetisation errors



Selected DIflux Topics: DIflux magnetic hygiene check

1. The best magnetic check is done by participating in workshops such as this one
2. Another check can be done by a second Diflux, installed in the I measuring position. DUT should be rotated in front of fluxgate and the extrema subtracted. !! Attention: the fluxgate sensor is magnetic
3. Inspection of the vertical I gradient ΔI gives indication of “non-hygienic” Diflux. ($\Delta I = I_H - I_L$)



Note: magnetic elements on the telescope do not introduce errors as long as they remain constant during the whole measurement protocol.

Absolute measurements are often synchronised at multiple of the round minute (variometer sampling rate). Therefore it is handy to be able to complete 1 measurement step in less than 1 minute.

Here some tips and tricks for speeding up the measurement procedure:

Operation of slow motion screws

Setting the telescope horizontal for D measurement

Selected DIflux Topics: Passing the 1 minute time barrier

<u>Operation of slow motion screws</u>

Principle: Always finish electronic-null seek by a clockwise motion: never reverse during null-seek! (avoid the « backlash » effect)

Therefore wait until 5s before full minute at ~1nT from null, on the side where you know you will reach null by clockwise motion. Then apply a quick screwing motion to find the null.

Setting the telescope horizontal for D measurement

Task: set the telescope horizontal so that the vertical circle reading is 90°00’00'' and coincidences are achieved.

For the Zeiss 010 and UOMZ 3TK2P theos, one needs therefore to set the micrometer to zero. This can be done quickly by rotating the micrometer counterclockwise until the mechanical stop – no need to look into the microscope. Then a quick look in the microscope and adjustement of micrometer will put it exactly at 0’00''.

Selected DIflux Topics

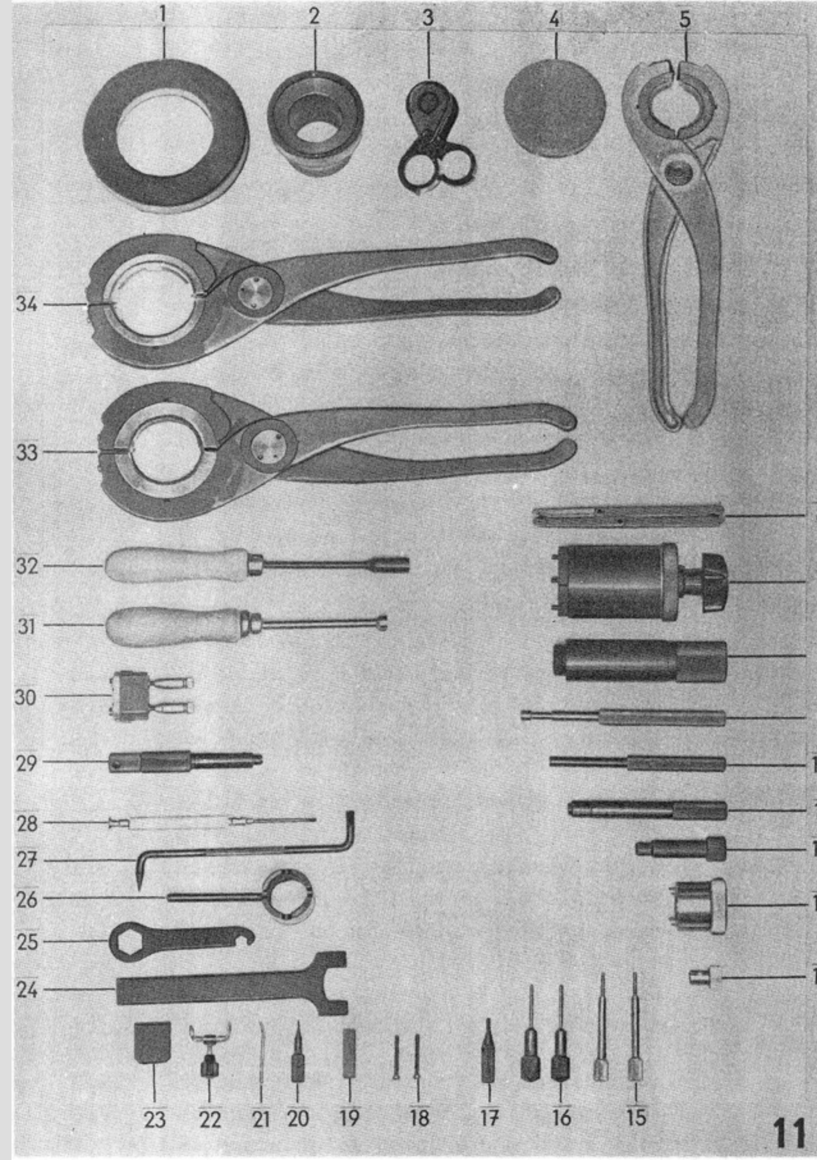
Specs of Theodolites

	Circle	Vertical index	Sys. errors
• Zeiss THEO 010:	+- 1’’	+- 0.3’’	none
• Zeiss THEO 015	+- 3’’	+- 1’’	eccentricity*
• Zeiss THEO 020	+- 6’’	+- 1’’	eccentricity*
• 3T2KP-NM	+-1”	+-1”	none
• YOM MG2KP (Russia)	+- 1’’	??	none
• Ruska theodolite	30”	Bubble levels	none

- *eccentricity errors are also removed using 4 positions

Selected DIflux Topics: Troubleshooting of the ZEISS 010/15/20

- ✓ <u>Caution:</u> do not troubleshoot a Zeiss theo if you are not at ease with fine mechanics
- ✓ <u>Caution:</u> always use the correctly sized screwdriver



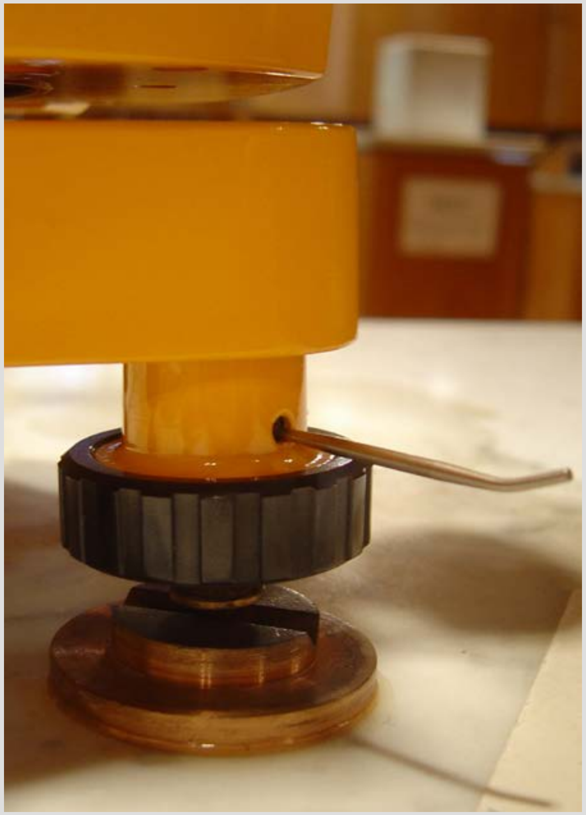
Special tools for repair of Zeiss theos

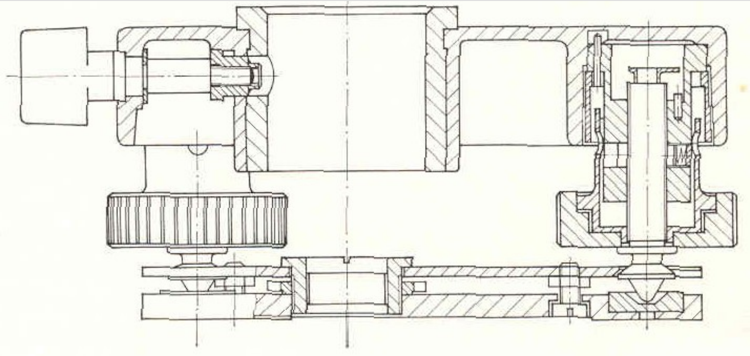
Selected DIflux Topics: Troubleshooting of the ZEISS 010/15/20

- If footscrews are loose you will have random horizontal circle reading errors and problems for levelling
- Therefore check regularly the footscrew play and adjust if necessary
- Footscrew play adjustement differs from theo type and series
- Below it is adjusted by tightening a screw, visible and accessible for a single specific position of the footscrew

Selected DIflux Topics: Troubleshooting of the ZEISS 010/15/20

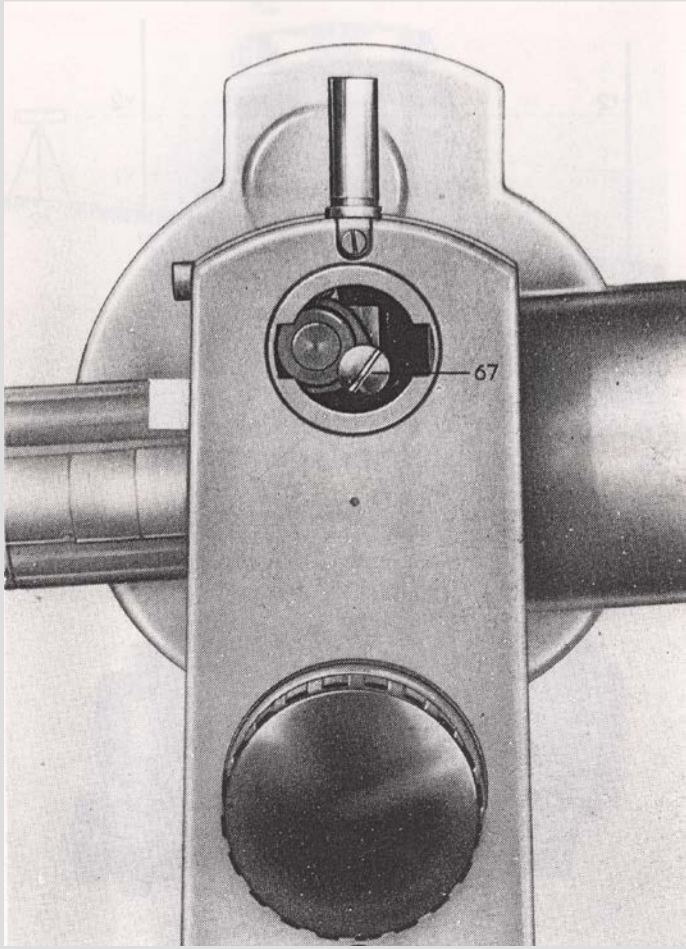
- Footscrew play adjustement differs from theodolite type and series
- Here it is adjusted by tightening the footscrew, after inserting a pin in the holes, visible and accessible for a single specific position of the footscrew



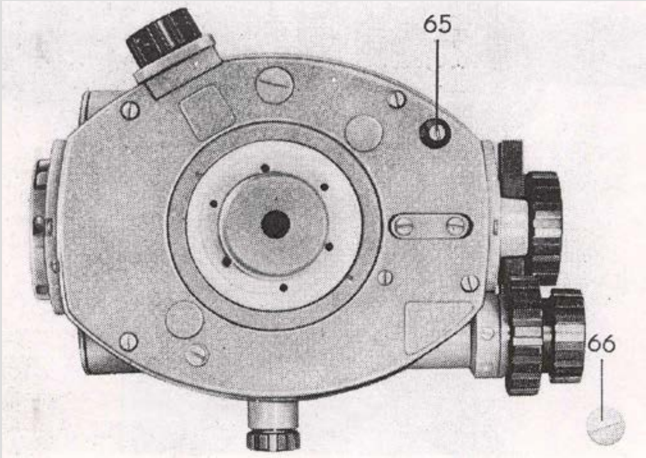


Selected DIflux Topics: Troubleshooting of the ZEISS 010/15/20

Horizontal axis clamp adjustment------------------→

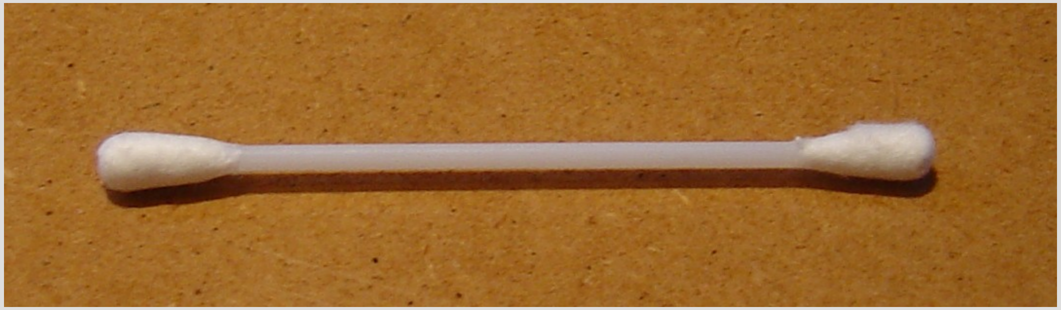


Vertical axis clamp adjustment ↓



Selected DIflux Topics: Optics cleaning

- Optics cleaning is difficult, so avoid dirtying them in the first place: never touch or contaminate the lenses and optical glass surfaces of the theodolite. (!! greases and lubricants)
- Valid tool for optics cleaning is cotton held on a brass needle. A fresh cotton tip is OK for easily accessible places.
- Golden rule: never reuse a cotton wad for optics cleaning.
- Cotton should be used dry (moderate dirt)
- Otherwise the correct fluid for optics cleaning is **ether**.



Total Field Measurements

- *Magnetic Induction units*
- *The preferred instruments: proton precession (Overhauser) magnetometers*
- *Instrumental Accuracy: Gyromagnetic constant; Time Base; Sensor magnetic Hygiene; Proton fluid; stabilizer calibration; Magic box*
- *Procedures for high accuracy: Timing; Distance to electronics; colocation with other Absolute instruments; "dF" measurements: « sensor exchange » method; Temperature influence on electronics*
- *Specs of commercial and other available devices*

Total Field Measurements: Magnetic Induction units

- The International System of Units' (SI) unit for magnetic flux density, which is used today in geomagnetism is the Tesla (T).
- In basic unit kilogram/second^2/ampere
- In geomagnetism 10^{-9} T = 1 nT is the most frequent used unit.

- At the Earth surface the total intensisy often named F varies from 25000 nT in the South Atlantic Anomaly to almost 70000 nT at the South pole.

- Older units like Gauss (1 Gauss = 100000 nT) may still be seen.

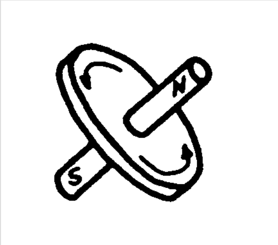
- Also the gamma (1 γ = 1 nT) has been widely used with geomagnetism.

Total Field Measurements: The preferred instruments: proton precession (Overhauser) magnetometers (Ole)

- Classical Proton Precession Magnetometers
  - High power consumption
  - Low sample frequency (20 sec)
  - Companies:
    - Geometrics
    - Elsec

- Overhauser Proton Precession Magnetometer
  - Low power consumption
  - High sample frequency (up to 0.5 sec)
  - Companies:
    - GEM system Overhauser PPM 0.2 – 3 sec
    - Quantum Magnetometry Laboratory Overhauser PPM

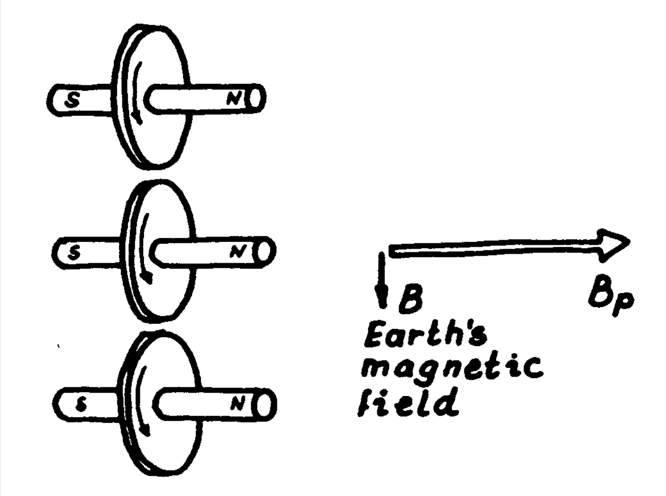
Total Field Measurements: The preferred instruments: proton precession magnetometers



- The PPM magnetometer is based on the free precession of protons in a liquid.
- The protons behave like small gyros with a magnet as axis.

- In a classical PPM´s a polarizing magnetic field Bp magnetize the liquid so that more proton gyros are aligned in the direction of the magnetic field than in the opposite direction.
- Only an eccess of $5*10^{-8}$

- The polarizing field is perpendicular to the Earth’s magnetic field .



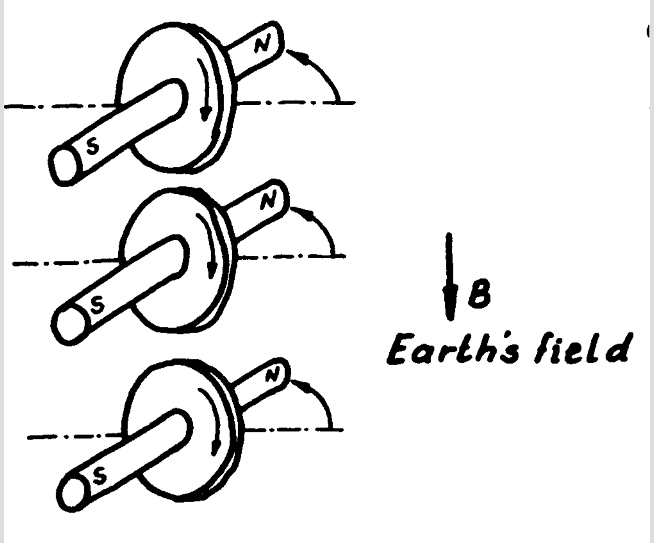
Total Field Measurements: The preferred instruments: proton precession (Overhauser) magnetometers

- When the polarizing field is switched off suddenly, all protons gyros start precessing (rotating) together around the Earth's field direction

- The ordered precession decays in a few seconds (in water).

- The precession frequency (2 kHz) f_p is proportional to the Earth's magnetic field
- $$B = 2\pi f_p / \gamma_p$$

- γ_p is a natural constant *the gyromagnetic ratio* which is known to a very high accuracy.



Total Field Measurements: The preferred instruments: Overhauser proton precession magnetometers

- In an Overhauser PPM one increases the magnetization of the liquid and therefore the precession signal by adding free electrons to the liquid. And utilises the strong coupling between the free electrons and the protons, which will transfer the polarization of the electrons to the proton.

- The magnetization of the electrons and protons is done by a suitable low power radio frequency. Whether as the classical PPM uses a high power polarizing field to magnetize the liquid.

- The generation of the precession signal can be done by a short pulse perpendicular to the Earth magnetic field. Or by a weak rotating magnetic field.

- The magnitization (signal) can be 1000-5000 stronger than for the normal PPM.

Total Field Measurements: Instrumental Accuracy:

- *Gyromagnetic constant*
- *Time Base*
- *Sensor magnetic Hygiene*
- *Proton fluid*
- *Magic box*
- *Stabilizer calibration*

Total Field Measurements: Instrumental Accuracy:

<u>Proton Gyromagnetic Ratio</u>

The proton magnetometer measures the magnetic induction **B** by observing the free precession frequency **f** of protons using the formula:

$$2\pi f = \gamma B$$

The quantity **γ** is the proton gyromagnetic ratio at low field for a spherical H_2O sample at 25 degrees Celsius.

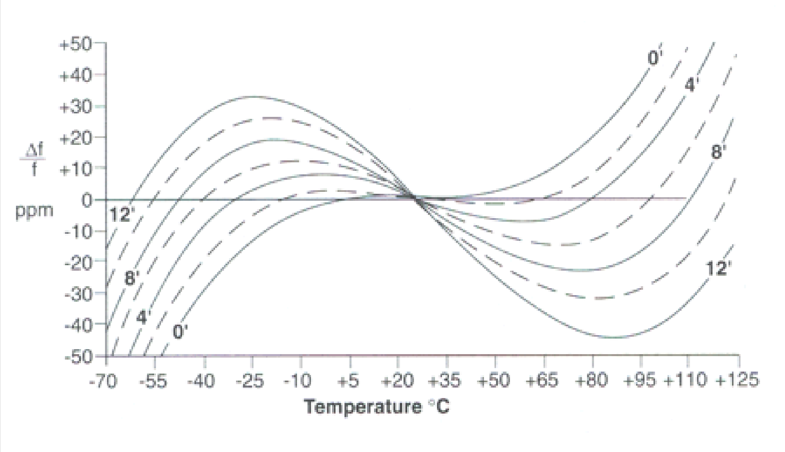
$$\gamma = 2.67515255 \; 10^{8} \text{ Hz/T}$$

Prior to 1992, $\gamma = 2.67513 \; 10^{8}$ Hz/T (IAGA resolution 1960)

Total Field Measurements: Instrumental Accuracy

Frequency Standard

- Magnetic Induction standard is replaced by Frequency standard
- Frequency standard: Good quartz oscillator
- So quality of quartz oscillator determines quality of magnetometer
- Quality of Quartz oscillator is affected by:
  - Long term drift (typically 0.5 ppm/year)
  - Temperature coefficient ----------------→



At a field of 50000nT, a quartz oscillator error of <u>10 ppm</u> will introduce a magnetometer error of <u>0.5 nT</u>

Total Field Measurements: Instrumental Accuracy

<u>Frequency Standard</u>

- Conclusion: standard should be checked at least once per year.
- Method:
  - Direct measurement of oscillator frequency
  - « magic box » (see later)

Total Field Measurements: Instrumental Accuracy:

Sensor magnetic hygiene

Sensor may be contaminated by « soft » or « hard » magnetisation

This is due to introduction of magnetic parts in the sensor materials (should not happen)

It will introduce a « Heading Error » which will change magnetometer reading when sensor rotates in a constant field

How to check?

1. Check anomalous proton signal decay in SUT*
2. Use DIflux check by rotating SUT in front of fluxgate (see before)
3. Use « piniok » method with SUT in various orientations

* SUT: Sensor Under Test

Total Field Measurements: Instrumental Accuracy:

Proton fluid

- Spectral line widths of liquid sensors : from 1 nT to 20 nT
- Spectral line widths (or decay time in pulsed systems) depend on temperature, gradient over the sensor and the type of liquid.
- All fluids have a <u>chemical shift</u> due to local magnetic fields produced by the atoms of the particular molecule.
- Span of all chemical shifts is 10ppm.
- Methanol is about 1ppm away from water at 25°C.
- Kerosene, widely used liquid in proton precession magnetometers is a mixture of chemicals and its chemical shift is not known. Kerosene spectral line is very wide, about 15 nT (decay time is about 0.5 sec dependent on temperature).

Total Field Measurements: Instrumental Accuracy:

<u>Magic box test of proton magnetometers</u>

Electronic signal from proton magnetometer sensors are very weak (~ 1µV)

When you feed the sensor with an known strong radiation at a frequency **f**, the mag will take it for the proton signal, measure its frequency and display the corresponding field value **B** given by:

$$\mathbf{B = 2\pi f/\gamma}$$

Since you know **f** and **γ,** this allows to check the frequency measurement accuracy of the mag (but not the sensor hygiene).

Total Field Measurements: Instrumental Accuracy

<u>Magic box test of proton magnetometers</u>

$$B = \frac{2 \times \pi \times f}{2.67515255 \times 10^{8}} [T]$$

Total Field Measurements: Instrumental Accuracy

Stabilizer calibration

Total Field Measurements: Procedures for high accuracy:

- *Timing*
- *Distance to electronics*
- *colocation with other Absolute instruments*
- *"dF" measurements: « sensor exchange » method*
- *Temperature influence on electronics*

Total Field Measurements : Procedures for high accuracy

Timing

When measuring a changing variable, timing is critical if high accuracy is wanted

However it is difficult to know when a measurement of the proton frequency is made after pressing « start »

There is the polarisation delay, and the integration time for frequency measurement is not always known, or worse, may vary with proton signal characteristic

Solution: Try to find out what is the timing of the mag:

- Inspect carefully the magnetometer’s manual
- Try to sind the polarization cycle by studying the current drain
- Examine when the proton signal is present

Total Field Measurements: Procedures for high accuracy:

<u>Distance to electronics</u>

Cables from sensor to electronics are often short

Batteries in electronics are often very magnetic

Check the effect from the electronics by performing a series of magnetometer readings while changing the electronics spatial orientation

To avoid contaminating effect from the electronics on the sensor:

- Try to install a longer cable (works well with Geometrics and Elsec)
- Power the electronics from a battery pack well away from them
- Order longer cable from manufacturer

Total Field Measurements: Procedures for high accuracy:

Colocation with other absolute instruments

When doing absolute measurements, the modern approach calls for an unique measurement location: the Observatory Reference Pillar

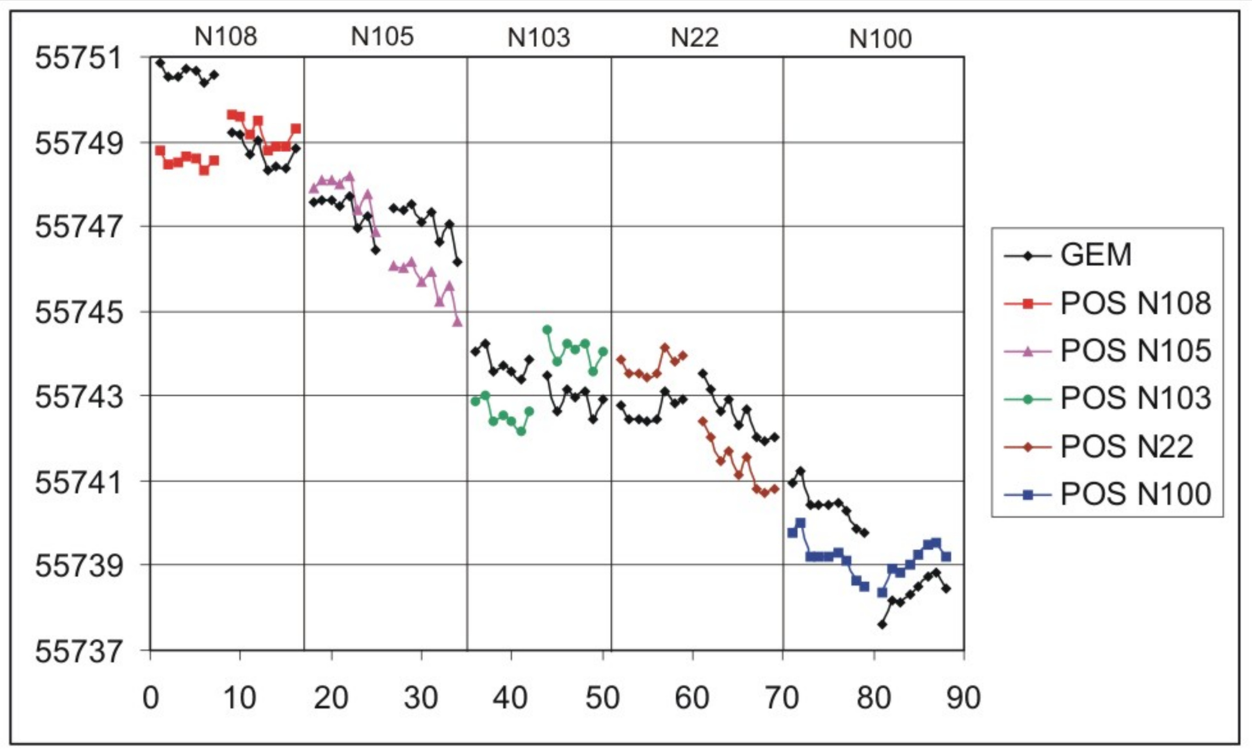
However, several instruments are involved in the vector measurements so they must be swapped on the reference pillar

Moreover, the proton magnetometer has often the continuous recording function, so practically it is set-up on another pillar which is supposed to have a constant difference (the delta F) with the reference

Accuracy calls for a good method to measure this delta F noted « dF »: the « sensor exchange » method

Total Field Measurements: Procedures for high accuracy:

"dF" measurements: « sensor exchange » method



Absolute Procedures for Observatory and Repeat Magnetic Measurements

ON OBSERVATÓRIO NACIONAL

Total Field Measurements: Procedures for high accuracy:

- Temperature influence on electronics