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DETECTION OF MECHANICAL INSTABILITY IN DI-FLUXGATE SENSORS

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SUMMARY

An important part of the declination-inclination (DI) measurement with the theodolite is to calculate the sensor parameters (horizontal and vertical misalignment, sensor offset). It is crucial to track these parameters over time, since the sensor has to be stable to give correct DI results. The Danish Meteorological Institute and now DTU Space have for many years produced DI-fluxgate electronics and used fluxgate sensors from Pandect. Some sensors were found to be unstable due to loose ferromagnetic cores inside, i.e., the vertical misalignment changes when the sensor is turned 'upside down' during the DI-measurement. We have found a way to glue the ferromagnetic cores within the new sensors to make them mechanically stable. All sensors are tested very carefully before being used. Since the observed erroneous sensor offset due to loose sensor usually is extremely high, we can use a fast method (called 'double offset') for a first check of the sensor. However, the definitive test of a sensor is the comparison of its offset measured in a zero-field chamber and the offset calculated from an absolute measurement.

1. DI-MEASUREMENT

A full DI-measurement with 4 positions for measuring declination (D), 4 positions for measuring inclination (I) and properly reading of azimuth marks will give the actual Earth magnetic field vector, helping to define variometer baselines, theodolite stability and sensor parameters (Lauridsen, 1985): Baselines: H0, D0 and Z0; magnetic field: D, I and F; azimuth mark angle; telescope misalignment; sensor scale factor; sensor offset: S0; horizontal sensor misalignment: ð or ð*H; vertical sensor misalignment: ε or ε*Z. Sensor offset is a combination of offset owing to the fluxgate sensor, cables and electronics. Sensor offset and misalignment can easily be plotted over time to keep track of changes.

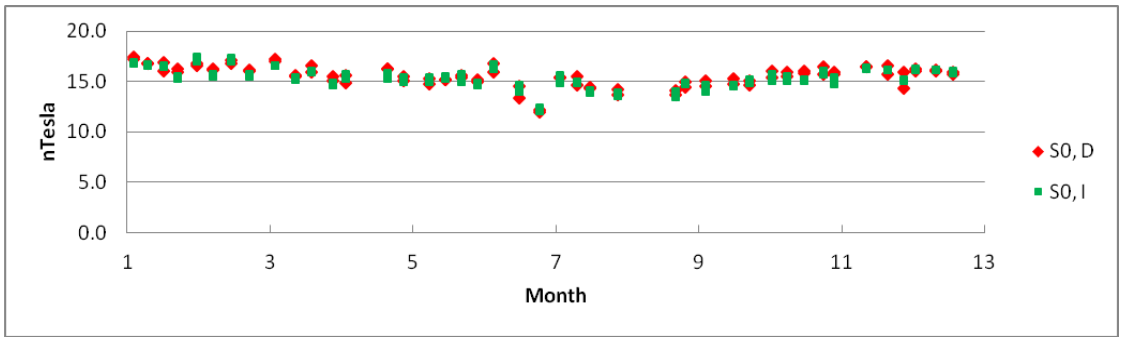


Figure 1 – Sensor offset S0 [nT] from D and I measurements, an example from Qaanaq (THL) observatory, Jan-Dec 2008.

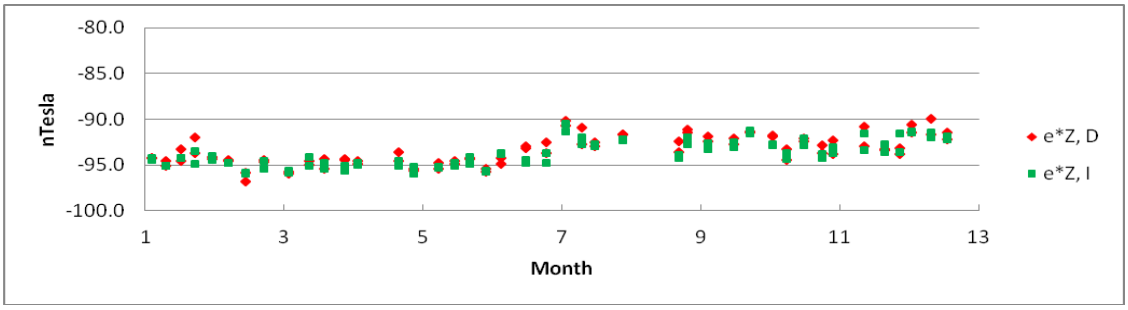


Figure 2 – Vertical misalignment ε*Z [nT] from D and I measurements. Qaanaq (THL) observatory Jan-Dec 2008

Figure 1 and 2 give an example of almost stable sensor offsets and misalignments from THL observatory in Northern Greenland.

The DI-measurement following the method described by Lauridsen (1985) is an absolute measurement and not relative like the 3-axial variometer. But its accuracy can be affected by many factors.

- **Timing:** the time of the DI-readings should be synchronized with variometer and proton magnetometer readings to a few seconds to avoid effects of changes in the magnetic field.
- **Magnetic cleanliness:** If the theodolite or other parts around it are magnetic, they will affect the local magnetic field and measured angles will be wrong.
- **Stability:** If pillars, telescope, sensor or azimuth marks are not stable, this will affect the DI-measurement.

Often, only baselines are plotted and controlled, and errors from other sources may not be seen in the data, and the variometer will be assumed to be unstable, even though this might not be the case. By plotting DI-parameters over time it should be possible to judge on the stability of the theodolite and the fluxgate sensor.

2. THE UNSTABLE DI-SENSOR

The Pandect sensor LDC-A20 is a widely used fluxgate sensor for DI-measurements. During the last 20 years DTU Space and DMI have produced more than 150 DI-instruments using this sensor.

In 2005 Pandect Company probably has made changes in the production of the sensor. In later years, high scatter in misalignment data from DI-measurement was seen for some instruments, without identifying the reason. In 2008, we received a theodolite from the Geological Survey of Sweden (SGU) back for inspection (unit LYC) that gave unstable readings of the offset (Figure 3).

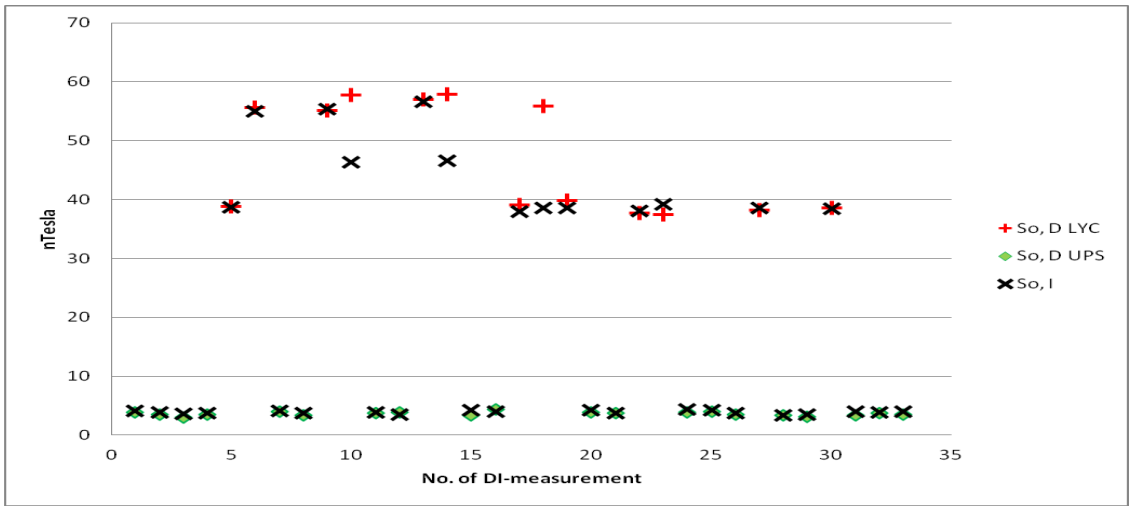
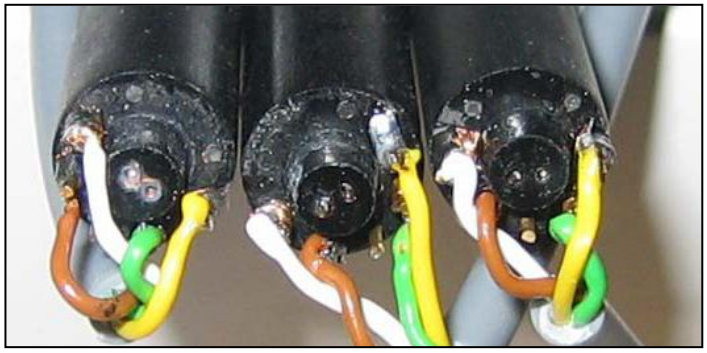


Figure3 – Sensor offset S0 [nT], measured by SGU during 5 month in summer 2008 from the LYC and UPS observatory.

Figure 3 show the large discrepancies that were observed in data from the LYC–system itself compared to the ordinary UPS-system.

Measuring with the LYC theodolite, we found a big discrepancy between S0(D), the sensor offset from D measurement and S0(I), the sensor offset from I measurement and S0 measured in zero field. We recognized that the problem could be due to loose ferromagnetic cores, as we could move the end of the core sticking out of the sensor with a very thin nonmagnetic stick. When we did this test with the Earth magnetic field perpendicular to the sensor we saw a big change in the output signal. In zero field, we observed no changes. This test indicated that the moving core changed the misalignment of the sensor but not the sensor offset. In the next paragraph we will show that it is difficult to distinguish between offset error and misalignment error during absolute measurements.



Picture 1 –Pandect sensors, in the middle of each sensor the 2 ferromagnetic cores can be seen.

Normally movements of the core in its tube are too small to be visible. But, we have observed this behaviour when rotating a sensor with loose core 'upside down'.

3. DOUBLE OFFSET METHOD

Before discussing how to measure the effect of loose sensors, we will describe the method for measuring the offset in a fast way, so that it can be done many times on each sensor.

With the sensor mounted on a theodolite in position 'North-up' and turned to position 'South-down', the sensor offset can be measured. (Actually it works in all 4 I-positions) As output, we get the residual that can be read on the display of the DI-electronics.

1:	Adjust output to zero in position 'North-up'	Example:
	Then the misalignment angle ε times F will be equal to the offset, i.e., **ε *F = S0**	
	Output = S0 – ε*F = 0	Output = 0.0nT
2:	Turn precise 180 degrees to position 'South-down'	Output = -6.2nT
	The misalignment is now opposite, i.e., -ε *F:	
	Output = S0 + ε*F = **2*S0** (1)	
	S0 = output/2	S0 = -3.1nT

If the core is tilting at angle α, misalignment will be α+ε

Output = S0 + (α+ε) *F	
Output = 2*S0 + α*F	Output=-32nT
Offset, S = S0 + α/2 * F	

Since the tilting angle α will vary over time depending on the handling of the telescope, the measured 'Double offset' will change over time. The 'Double offset' method can also be applied when changing from position 'South-down' to 'North-up', i.e., when the theodolite is turned back into starting position. It will then give a second reading of offset and sensor tilting.

4. REPAIR AND CONTROL OF SENSORS

Measurements show that cores are only loose at one end, here called the 'top'. At the 'bottom', the cores are glued by the producer, but not at the top to allow for temperature expansion. We now glue the core in the top with silicone in vacuum, so the silicone can penetrate into the thin tube. By using silicone and not a 'hard' glue, we avoid mechanical stress in the cores and observe no temperature drift of the sensor output (offset).

After glueing we now control the sensors in the following ways:

- Each sensor is visually inspected under the microscope to check that cores are not loose.
- Sensors are placed in our 'zero field' cylinder and the offsets are measured to see stability over time.
- In the observatory sensors are mounted on a test theodolite, and offsets are measured using the 'Double offset' method to see if cores are stable. The sensors are rotated 4 times in steps of 90 degrees during this test, with the label (showing the serial number) being oriented 'text up', text right', 'text down' and 'text left'.
- Accepted sensors and DI-electronics are combined and adjusted to low offset with the sensor in the zero-field chamber.
- A careful DI-measurement is made as a final test for each sensor and its electronics. If the ferromagnetic core is tilting when the

telescope is inverted, this results in an erroneously high sensor offset. By comparing the sensor offset determined in zero field (true value) and with a regular DI-measurement (erroneous value), loose ferromagnetic cores can be identified.

Picture 2 – Pandect sensor mounted in a cradle with nonmagnetic springs for fast replacement or rotation.

5. RESULTS

Table 1 –offset [nT] measured with 'Double offset' method

Sensor	Good /bad	Offset in zero-field		Measured 'Double offset', sensor is rotated into 4 positions					Half DO
No		start	end	0 degr.	90 degr.	180 degr.	270 degr.	360 degr.	mean/2
7365	/	-3.4	-3.6	-5.6	-5.5	-7.2	-5	-5.2	-2.9
7399	v	-4.9	-4.9	-8.1	-7.9	-8.3	-8.3	-8.0	-4.1
7400	v	-4.6	-4.4	-8.5	-7.1	-7.4	-8.4		-3.9
7401	v	1.8	1.9	5.0	3.5	4.5	3.8	4.5	2.1
7402	v	-3.8	-3.8	-7.1	-6.4	-6.1	-7.0		-3.3
7403	/	-1.9	-2.2	2.4	5.5	6.2	2.2		2.0
7406	v	-4.7	-4.7	-8.0	-8.1	-8.0	-7.9	-8.1	-4.0
7407	v	-2.7	-2.6	-5.7	-4.5	-6.6	-5.0		-2.7
7408	v	-6.4	-6.7	-9.8	-10.9	-9.4	-9.7		-5.0
7409	v	-4.2	-4.2	-8.2	-8.1	-8.8	-7.2		-4.0

Table 1 shows the offset from both good and bad sensors. The offset of sensor 7403 (bad sensor) is changing a lot (4 nT) when tested in different positions and in zero field. In the same way we have measured 10 older sensors produced before 2005. They all deliver very stable results.

6. CONCLUSION

It is possible to repair most sensors with loose cores. With the described test routine, we can find all bad sensors. The 'Double offset' method is a quick but not a precise method to determine sensor offset without completing a full DI-measurement. The varying Earth magnetic field is not considered in this procedure. Therefore, measuring the offset has to be done fast to avoid errors in readings due to changing magnetic field. The adjustment of the angles of the theodolite has to be very precise, better than 2 seconds of arc.

For a conclusive test of the sensor, the sensor offset is measured in a zero-field chamber and calculated from a normal DI-measurement as well.

7. REFERENCES

Lauridsen, E.K., 1985. Experiences with the DI-fluxgate magnetometer. Geophysical Papers R-71. Danish Meteorological Institute, Copenhagen.