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Monitoring of Long Term Mechanical Stability of a Suspended dIdD Sensor applying Optical Observation

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ABSTRACT

Automatic geomagnetic measuring systems need additional solutions to monitor the variation of the reference frame of the sensor. Reference frame of a vector magnetometer is defined physically by the true direction of sensor's axes. Several methods have already been developed for establishing the correct adjustment of the sensor. Published methods were suitable to align the sensor but continuous monitoring of the reference frame was not ensured especially for declination measurement without an independent reference magnetometer. Introduction of the so called MGEN device to measure optical angle variation between the suspended dIdD sensor and an independent telescope is a new promising improvement. MGEN device was originally designed for astronomical monitoring purposes, but with some modifications it can be used to monitor small movements and rotation of nearby objects like magnetometer sensors. Our paper presents the device and the first long term results of the measurements.

Keywords: Reference frame, Optical monitoring, DIdD, Baseline.

INTRODUCTION

Several methods were developed to help the installation of magnetometers (necessary to add couple of references). Different types of magnetometers need different procedures to find the perfect orientation of the sensor. The user manuals give usually good instructions for the observers how to perform the installation. The manufacturers of magnetometers often provide certificate of the calibration too. However, after setting up the device the tilt of the pillar or variation of the temperature can modify the originally developed reference frame of the sensor. Suspension of the sensor can eliminate the tilt of the device but torsion of the system still can happen despite of the applied suspension. Unfortunately, different sources of errors (i.e. mechanical instabilities, temperature effect on the device, voltage dependence of electronics etc.) appear simultaneously. There are no general solutions to separate these errors and to correct the dataset afterwards. Usually, the observers summarise these errors as the variation of the baseline.

If we could independently monitor the mechanical variation of a sensor then we would have a better chance to identify the main reason of a baseline drift. This idea is more realistic if our device is essentially free from a few possible calibration errors.

From this point of view the advances of dIdD instrument become even more important:

Since the dIdD system is based on a nuclear magnetometer, this instrument can be qualified based on parameters of the nuclear magnetometers, i.e. accuracy, sampling interval etc. It also follows, that the scale factor and the offset do not need to be calibrated.

Only the following four values have to be calibrated for the determination of the reference frame of the device:

i.) I_0 value (I baseline),
ii.) D_0 value (D baseline),
iii.) orthogonality error of magnetic axes,
iiii.) the levelling error of the D coil axis.

By summarising above points, one can conclude that the dIdD reference frame is defined physically by the D coil and I coil axes. They should be orthogonal and the D coil should be horizontal, in the case of perfect alignment of the sensor.

The dIdD instrument provides good baseline stability. If we assume that the magnetic axes of the sensor is determined only by the mechanical position of the coil system then we should only monitor the coil's direction in the geographic reference frame and the orthogonality of the coil system.

The direct measurement of the orthogonality is resolved by current switching between the coils (*Heilig 2012*). Similar solution can be used for I baseline and for levelling of the D coil axes by applying suspended turning coil (*Hegymegi 2012*).

In order to have good information about the variation of declination baseline, the Lacerta MGEN autoguider optical device was incorporated into the system, to monitor the position of the sensor in horizontal plane. For this monitoring a reference point is required at a certain

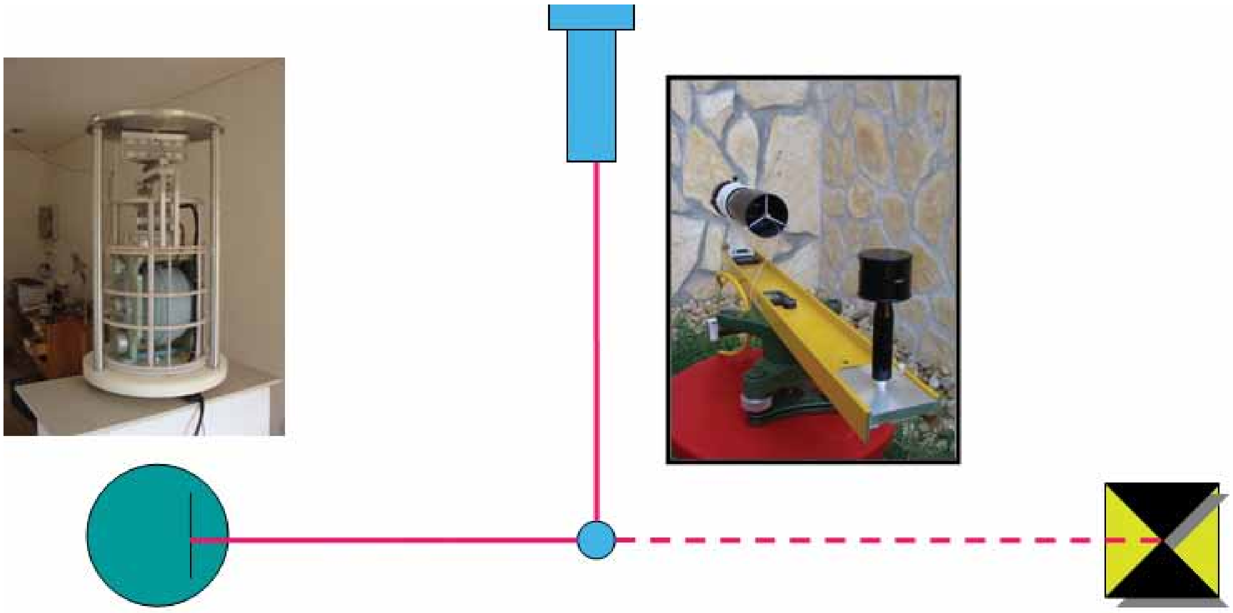

Figure 1. The configuration of the optical monitoring system

distance from the sensor. When we designed this system, our main goal was that the measurement resolution should be high enough if using in-the-room reference, or external reference (for example a point equipped with a GPS) at a bigger distance.

THE OPTICAL UNIT AND THE MEASURING SYSTEM CONFIGURATION

The Lacerta MGEN device was originally designed for astronomical applications. In order to use it for our tasks we needed to modify the unit.

Theoretically the D baseline of the dIdD is equal to the angle, which is measured between the true North and the plane perpendicular to D coil axes. In the observatory practice we need to measure only the variation of this direction if we have a chance to calibrate this value from time to time. If we attach a mirror on the suspended part of the dIdD sensor we can measure this variation directly. In this case it is enough to monitor the position of the light, which is reflected by the mirror.

In our test configuration the light is emitted by a small LED from the centre of the telescope. A prism turns the direction of the light at right angle to the mirror of dIdD sensor. The way of the light is practically the same back to the telescope (Figure 1.).

The MGEN device continuously calculates the centre of the light beam in the camera as X/Y sub-pixel values, and sends these horizontal and vertical coordinates to the data logger in 0.001 pixel-point resolution. This set-up is able to monitor the mutual positions of the camera and the mirror with very high resolution.

Technical specification of the camera:

CCD size	752x582 pixel
	2.7x3.65 mm
Depth	8 bit
Reading velocity	2 Mpixel/sec
Power consumption	
w. electronics	12 V DC
	max 200 mA
Operating temp.	-10 to +60 °C

A double prism system applied, where one prism directs the light to the mirror of the instrument and the other to the remote mirror. By screening one or the other the camera can measure the two angles.

In Tihany Observatory the calibration of the MGEN output is possible with absolute measurements on the absolute pier of the observatory. Therefore external reference mark was not used.

CALIBRATION OF MGEN DEVICE

Other question is the scale factor and the linearity of the MGEN device. In order to determine these parameters a calibration procedure was performed in Tihany Observatory (THY). The suspended sensor of dIdD was rotated along its vertical axis with several minutes of arc. After measuring for five minutes in the new position, rotation was performed again, and this cycle was repeated several times. The MGEN device recorded the actual values of rotation during the test. The true angle of rotation was calculated as a difference between the standard observatory declination data and the actual declination record of dIdD. The result of comparison of the two independent measurements shows

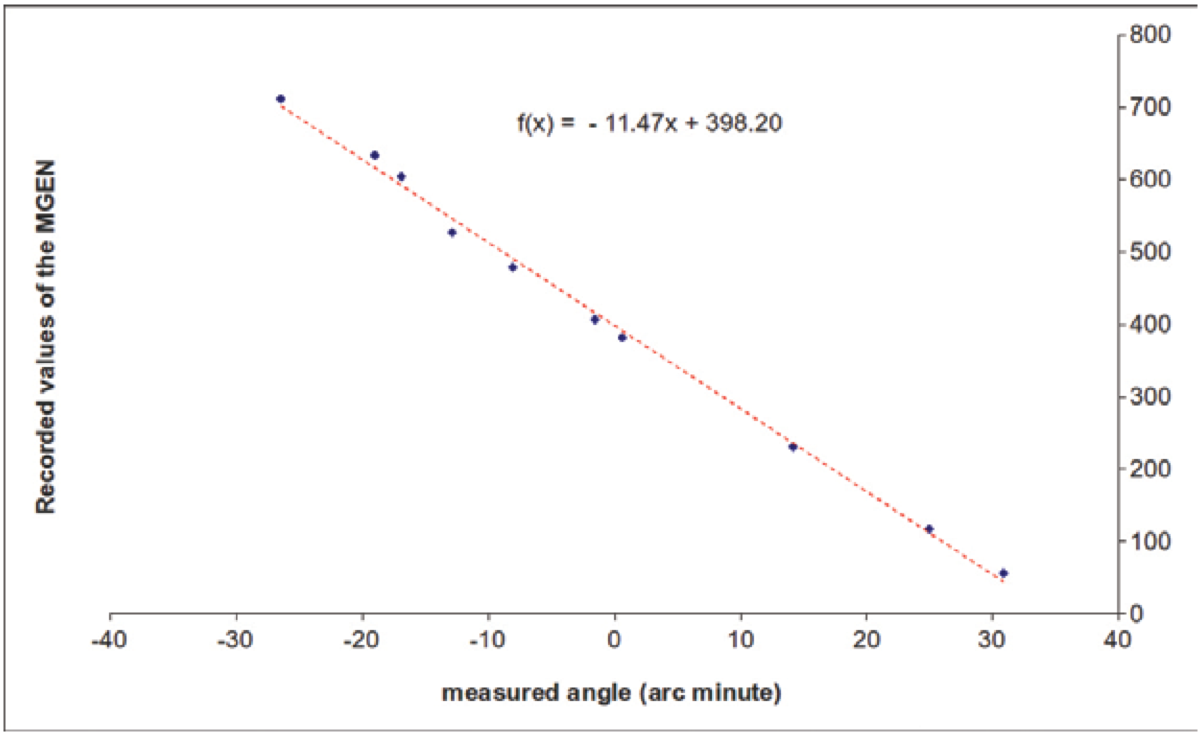

Figure 2. The result of the calibration of the MGEN scale factor

that the linearity of MGEN device is good in the whole range i.e. 0-800 pixels (Figure 2.). The distance between the camera and the dIdD sensor was about 2.5 meters. The result of this measurement shows also that one pixel variation in MGEN corresponds to 5.23 arc second rotation of the dIdD sensor. The noise level of the system 0.03 pixels peak to peak gives about 0.16 arc second resolution.

The residuals of the procedure were processed too. The maximal values of the residuals did not exceed the range of 13 pixels. The residuals may come from the optical error of the telescope or the mirror.

LONG TERM dIdD BASELINE STUDY WITH MGEN

In order to test the utility of D baseline monitoring, we performed a long term measurement in THY from, during 16.08.2013 to 28.11.2013. The dIdD device was installed in the old variation house of the observatory. The declination baseline of the dIdD was monitored in two independent ways. We compared the output of the dIdD with the definite data of THY and with the MGEN record too. The temperature of the room was also recorded at two points with 0.001 °C resolution.

The variations of D baseline are presented with the temperature and the MGEN record (Figure 3). We used minute mean values for this study.

In this paper we analyse only the declination measurements of the instruments. Earlier studies (*Csontos 2012*) presented that the declination output of dIdD mainly depends on the direction of D axis (D_0 value). We found that the inclination base of the device was stable within 10 arc seconds during the study. The attenuated variation of the inclination base brings out rate of stability. We have noticed that the orthogonality of the coils, the horizontality of the D axis and especially the I_0 value were very stable during our test. As a consequence we can be sure that the variation of the declination base essentially indicates the variation of the D_0 value.

The declination baseline of dIdD device varied more than 40 arc seconds in the studied period. The MGEN record in horizontal plane shows about 25 arc seconds variation. The variation of the temperature does not show strong correlation with declination baseline. The MGEN record of horizontal rotation is more or less similar to temperature variation. This indicates a temperature effect on the mutual position of the devices or on the MGEN measuring system only.

A close observation of varied activity during entire test period helps in better evaluation of correlation between the dIdD baseline and the measured temperature. The close observation revealed that mechanical variations seem to be low. However, if we observe the curves from about day number of 270, then a better correlation (but with negative sign) can be realized.

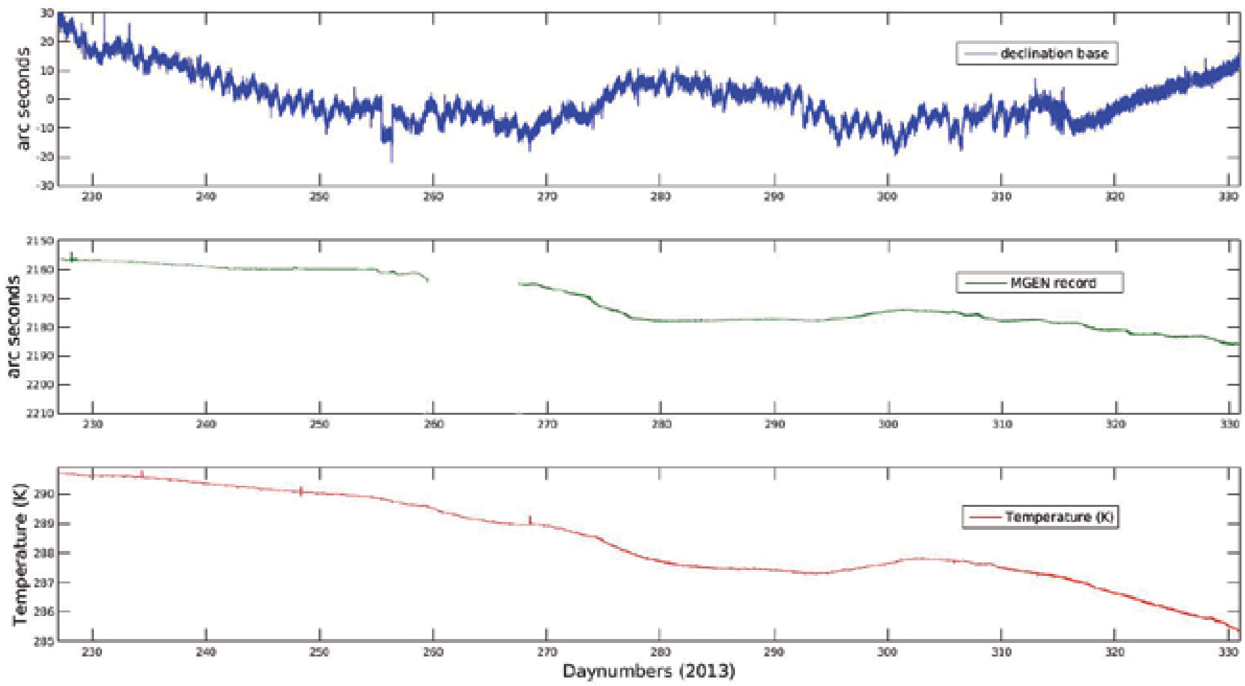

Figure 3. Difference values between the definite THY declination variation and the corresponding dIdD output, MGEN record of horizontal rotation and the temperature record

Further tests are required to find out the reason of this experience.

FURTHER MECHANICAL EFFECTS IN THE DATASET

The appearance of "beginning drift"

After the installation of a magnetometer one usually notices appearance of a baseline drift. This drift is usually significant and its characteristic is exponential. During several tests we found similar effect in the MGEN record too. The device presented two minutes drift during two weeks, even though temperature was stable during this test. This experience shows that mechanical reasons of the "beginning drift" can be significant.

Earthquakes in the record

Several earthquakes (5 and 3 ML were the typical magnitude) occurred in Hungary in the period of the long term test. The centre of the earthquakes were about 200 km away from THY. The seismograms from a nearby Tihany seismograph station were available. The MGEN records during period of earthquakes were always disturbed. The amplitude of the MGEN "noise" always related to the seismograms from Tihany station.

CONCLUSIONS

We developed and tested a new optical device (MGEN) for geomagnetic monitoring purposes. The instrument measures the mutual direction of the camera and the target device. We found that the MGEN provides perfect stability for observatory tasks. The linearity and the resolution of the instrument are also good. The long term test shows that this monitoring system is also sensitive to the temperature variations.

In our first long term test we found that the expected correlation between the dIdD declination baseline and the measured temperature and mechanical variations is not always obvious. Probably the variation of the D_0 value is caused by different reasons not only the mechanical instability.

However, the observed mechanical effects i.e. "beginning drift" and the disturbances in the MGEN record during the time of the earthquakes show that the device is really efficient for the tasks.

This instrument can be a candidate solution of automatic observatories for monitoring the mechanical stability of the sensors.

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