J. Ind. Geophys. Union (January 2016)
Special Volume-2/ 2016 pp: 42-46

The Temperature Stability of LEMI-025 1-Second Variometer: Case Study in the Icheon Observatory

Sooncheol Hong [1], Jung-Hoon Kim [1], Andriy Marusenkov [2], László Hegymegi [3], András Csontos [4]

[1] SETsystem, Inc., 16-3 Gangnamdaero 8, Seocho, Seoul, Korea,
kim@setsystem.co.kr

[2] Lviv Centre of Institute for Space Research of NANU and SSAU, 5A Naukova St., 79040, Lviv, Ukraine,
marand@isr.lviv.ua

[3] Mingeo Ltd., H-1142 Budapest, Ráskai Lea u. 20, Hungary,
hegymegi@mingeo.com

[4] Geological and Geophysical Institute of Hungary, Tihany Geophysical Observatory, H-8237
Tihany, Kossuth utca 91,
csontos.andras@mfgi.hu

ABSTRACT

The temperature characteristics of the 1-second variometer were studied in the real operation environment. For estimations of the instrument thermal drift the two approaches based on the total field difference and base values analysis were used. The total temperature drift was decomposed to the console and the sensor ones using considerable differences in the temperature variations of these units. The significant non-linearity of the temperature dependencies of the variometer electronic unit was revealed. The temperature corrected total field difference did not exceed ± 0.5 nT during about one year.

Keywords: Variometer, Sensor, Temperature drift.

INTRODUCTION

The South Korea Icheon geomagnetic observatory, which belongs to Korean Space Weather Center (KSWC) of Radio Research Agency (RRA), was upgraded in May-June, 2013. The new places both for the recording instruments as well as for the absolute measurements were built. The new set of the recording instruments includes the Overhauser magnetometer GSM-19, the fluxgate magnetometer LEMI-025 with the gimbals suspended sensor, the data acquisition system MAGREC and DI-flux meter for performing absolute measurements. As a result of the proper installation the devices were free from possible instrumental errors i.e. inaccurate scale factors, orientation errors etc. Due to the underground installation at the depth approximately 3 meters, the Overhauser and fluxgate sensors' temperature daily variations are quite small (0.1 – 0.3 Celsius degree). In contrast, the consoles' diurnal temperatures vary considerably (up to 10 Celsius degrees). The sensor and console temperatures have also significant seasonal variations (Figure 1, curves Ts and Te respectively). The aim of the present study is to estimate the temperature drift of the LEMI-025 magnetometer in the real operation conditions. Two approaches for estimation thermal drift were used: a) the comparison of the total field time series computed using the variometer records with the scalar magnetometer data; b) analysing the variometer base values obtained as a result of the absolute measurements.

DATA PROCESSING – THE TOTAL FIELD DIFFERENCE ANALYSIS

In accordance with the first approach, the total field values computed using bias fields and the variometer 1-minute data were compared with the Overhauser magnetometer records – so called delta-F test – the common INTERMAGNET observatories practice for data quality control *(INTERMAGNET TECHNICAL REFERENCE MANUAL, 2012)*. This method was usable only to test the H and Z components. (The contribution of D component to the calculated total field value is practically zero.)

The data were analyzed separately at the two intervals: a) from September, 11th, 2013 till March, 14th, 2014; b) from March, 28th till August, 26th 2014. The variometer bias fields applied at each interval were slightly different; as a result some shift between dF values at each interval exists (Figure 1, curve "dF").

Taking into account different behaviours of the electronic unit (Te) and sensor (Ts) temperatures the attempt to separate the contributions of the temperature drifts of the console and the sensors was made.

In order to separate effects of the sensor and console temperatures on dF we select the subintervals with approximately stable sensor temperature T_s (with maximal deviations <1.6 °C) and built the plots dF vs. the console temperature T_e. In this plot dF – Te points from each interval are concentrated near some average line. However, the dF values taken at the same Te, but from the different subintervals, are shifted, as we assumed, due to the influence of the sensor temperature Ts. Correcting these shifts between

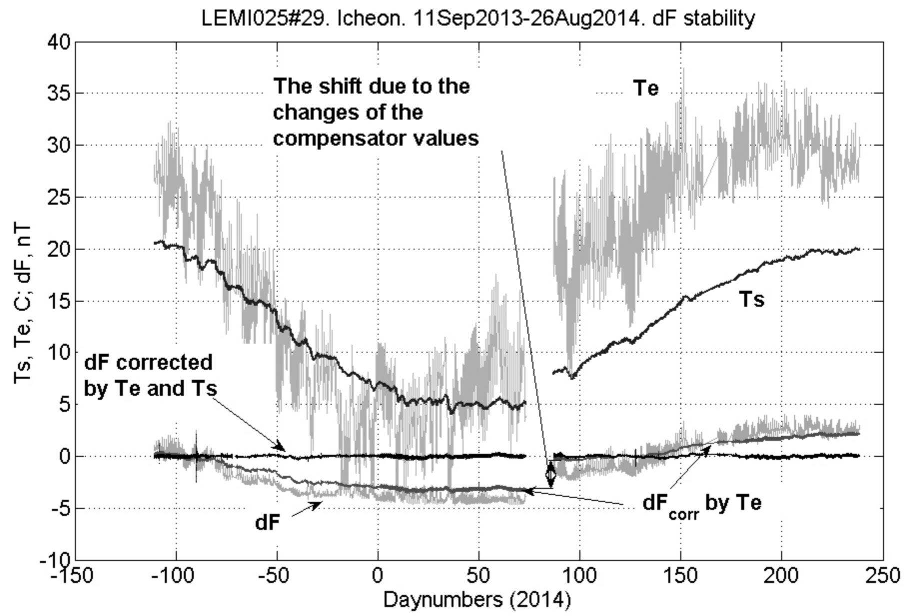

Figure 1. The total field difference (dF) and the magnetometer temperatures.

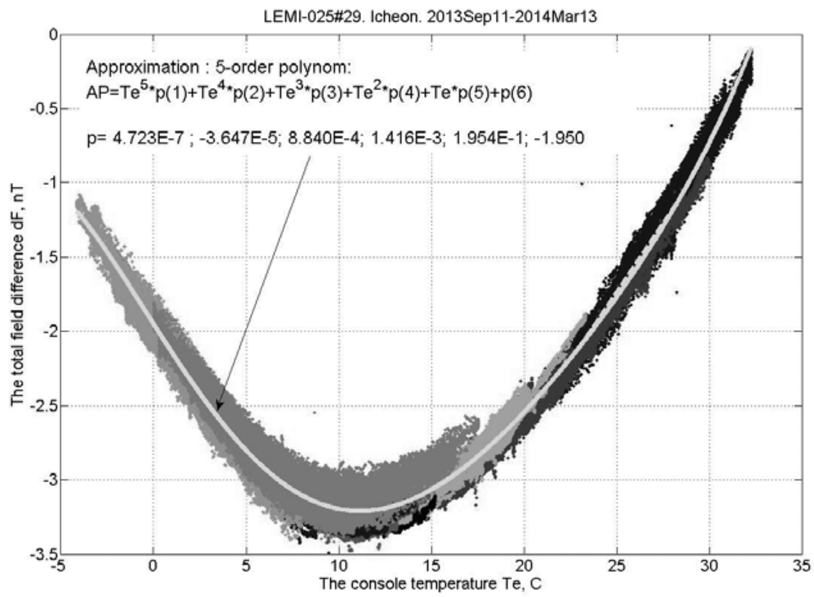

Figure 2. The total field difference (dF) dependence on the console temperature. The data subsets with the nearly constant temperature of the sensor are marked by the same grey colour hue.

subintervals the common set of the pair dF-Te was combined and, then, approximated by the 5-order polynomial fits (Figure 2). It has to be noted that the dependency dF on the console temperature Te is strongly non-linear and even changes its sign at the proximity of Te≈10.5°C. The non-linear dependencies at the both intervals are consistent and satisfactory correlate with thermal drift specifications of the voltage reference LTC1027, used in the variometer, and with the results of laboratory tests of the compensator current thermal stability, which creates the bias fields. So, we assume that drifts along H and Z components are caused by the common source – the voltage reference. Therefore, these drifts are proportional to the bias values along these components and could be corrected using thermo-drift estimations based on the dF analysis.

After correcting the console temperature dependence by polynomial approximation (curve "dF_{corr} by Te" in Figure 1) we estimated the sensor temperature influence

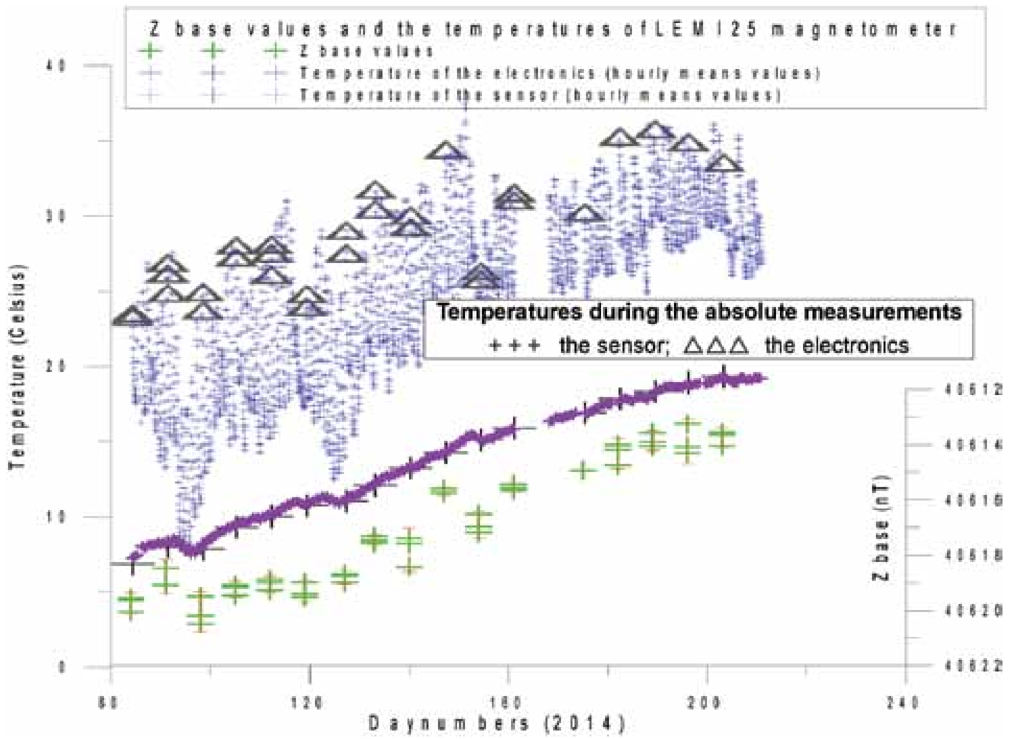

Figure 3. Variation of the temperature and the Z base values of LEMI-25 device

basing on its seasonal variations. The dF values also show non-linear dependence on the sensor temperature – the 3-order polynomial approximation was used to correct this dependence. The dF values after correcting temperature drifts and the shift due to the bias values change are given in Figure 1 (curve "dF corrected by Te and Ts") – there is no observable long-term drift and all corrected values do not exceed ± 0.5 nT during one year.

DATA PROCESSING – ANALYSIS OF BASE VALUES

We selected a period of the data set which was mostly free from instrumental problems. We used the 1st, 2nd and 3rd complete set of daily absolute measurements for our work. We discarded the absolute values, if we found extreme outputs of the diagnostic parameters I.e. the misalignments and the offset of the sensor.

Figure 3. shows the variation of the temperature and the Z baseline during 130 days. We can see the different characteristics of the two temperature variations. We can also notice a significant temperature effect on the Z component. In Figure 3. it is clearly seen that the fluctuations of the measured temperatures (sensor and electronics) at the time of absolute measurements has a different behavior. This different fluctuation of two temperature variations give us the chance to separate temperature effects on the sensor and the on the electronics.

The next step was the computation of temperature coefficients. We used numerical optimization. We calculated the temperature corrected base values(Z_{BC}): $Z_{BC}=Z_b+(T_s-10)*Z_{CS}+(T_e-20)*Z_{CE}$, where Z_b is calculated Z base, T_s is the temperature of the sensor, Z_{CS} is temperature coefficient of Z sensor, T_e is the temperature of the electronics, and Z_{CE} is temperature coefficient of electronics. Let us note, that the drift of base values always has the opposite sign in respect to the magnetometer drift, because the sum of the base values and the variations yields the real value of the measured component almost free from the instrumental errors. We selected the sign of the coefficients Z_{CS}, Z_{CE} in such a way, that it represents the polarity of the temperature drift of the magnetometer data.

We used hourly means of Z sensor and electronics' temperature values corresponding to each absolute set of measurements. We assume that only the temperature dependence has caused the drift in baseline values . In such a case temperature corrected base values should be free from any drift and any scatter too. We also supposed that the temperature dependence is a linear function of temperature and it does not vary in the time. Of course, our assumption about linearity of the temperature dependence is not completely correct, especially for the electronics drift, as it was revealed by the delta-F analysis. However, during the absolute measurements the electronics temperature mostly fluctuates between 15-35 °C and in this range the magnetometer temperature dependence could be satisfactory approximated by the linear function

Table 1. Console temperature coefficients (Te=15 – 35 °C)

	dF estimations	Base values' estimations
B_H=30160 nT	0.12 nT/ °C [1]	(0.04 … 0.05) nT/ °C
B_Z=40620 nT	0.16 nT/ °C [1]	(0.14 … 0.16) nT/ °C
F=50593 nT	0.2 nT/ °C	0.16 nT/ °C [2]

[1] calculated in assumption of the common source of the thermal drift — the voltage reference thermal dependence
[2] the value calculated from the components' temperature coefficients

Table 2. Sensor temperature coefficients (Ts=15 – 22 °C)

	dF estimations	Base values' estimations	Difference
B_H=30160 nT	0.15 nT/°C [1]	-(0.2 … 0.23) nT/°C	-(0.35 … 0.38) nT/°C
B_Z=40620 nT	0.2 nT/°C [1]	0.46 … 0.47 nT/°C	0.26 … 0.27 nT/°C
F=50593 nT	0.25 nT/°C	0.24 … 0.25 nT/°C [2]	**≈0.0 nT/°C** [2]

[1] calculated in assumption of the common source of the thermal drift — linear thermal expansion of the compensation windings
[2] the value calculated from the components' temperature coefficients

(see Figure 2). Previous studies show that the most of the fluxgate magnetometers have large temperature coefficients and their behaviour depends significantly on the amplitude of the temperature change. Thus, the determination of a general temperature coefficient, as a correction factor is very limited *(Csontos, 2007)*. Anyway, the instrumentation of a common INTERMAGNET observatory let us to use only the presented methods for base value correction especially in the case of D component.

In our case 42 complete sets of absolute measurements were corrected for temperature. We selected the maximum of corrected values [MAX(Z_{BC})] and the minimum of the same values [MIN(Z_{BC})] after every numerical iteration. Our task was to find the minimum of MAX(Z_{BC})-MIN(Z_{BC}) expression by applying different coefficient values. The corresponding temperature coefficients are Z_{CS} = 0.46 nT/C° and Z_{CE} = 0.14 nT/C°. Using similar method we determined the temperature coefficients of the two other sensors. In the case of H sensor we found: H_{CS} = -0.20 nT/C° and H_{CE} = 0.04 nT/C°. For the D sensor D_{CS} = 0.07'/C° and D_{CE} = -0.03'/C°, where H_{CS} is a temperature coefficient of H sensor, D_{CS} is a temperature coefficient of D sensor, D_{CE}, H_{CE} is temperature coefficients of the electronics. We find that in the case of D component that the residuals are significant. The original drift of D component did not show any similarity with the temperature variation.

Alternatively the RMS value of the 42 temperature corrected absolutes set was processed too. Numerical iterations were performed to determine the temperature coefficients. The predefined expectation was that the RMS of temperature corrected absolute measurements should be minimal.

In the second case the corresponding temperature coefficients are Z_{CS} = 0.47 nT/C° and Z_{CE} = 0.16 nT/C° and H_{CS} = -0.23 nT/C° and H_{CE} = 0.05 nT/C°. Our conclusion was that the result does not depend significantly on the method used to obtain coefficients.

RESULTS AND DISCUSSION

We compare the estimations of the LEMI-025 temperature drift coefficients based on the total field difference and the base values methods. The base values estimations were conducted only at the limited time interval from March, 28 till August, 26th 2014, when the sensor temperatures mostly varied in the range 15-22 °C and the console temperatures – in the range 15 – 35 °C. In these temperature ranges the non-linearity of the thermal characteristics is not very strong, so we compare the temperature coefficients of the linear approximations of the temperature drifts (Table 1 and Table 2). The delta-F estimations of the components' temperature coefficients H_{dFs}, H_{dFe}, Z_{dFs}, Z_{dFe} were calculated using following expressions:

$$H_{dFs} = F_{dFs} \cdot B_H / F \ , \ H_{dFe} = F_{dFe} \cdot B_H / F \ ,$$
$$Z_{dFs} = F_{dFs} \cdot B_Z / F \ , \ Z_{dFe} = F_{dFe} \cdot B_Z / F \ ,$$

where F_{dFs}, F_{dFe} – the total field difference sensor and electronics temperature coefficients;
B_H, B_Z – horizontal and vertical components of the magnetic field;
F – the total field intensity.

The base values' estimations of the total field difference temperature coefficients F_{CS}, F_{CE} were calculated as follows:

$$F_{CS} = (H_{CS} \cdot H_{CS} + Z_{CS} \cdot Z_{CS})^{1/2} \ , \ F_{CE} = (H_{CE} \cdot H_{CE} + Z_{CE} \cdot Z_{CE})^{1/2} \ .$$

Both approaches give the mutually consistent estimations of the console temperature drift (Table 1). The small difference in the H component drift estimations could be explained by the deviation of the drift from the linear dependence.

The H and Z sensors' temperature drift estimations based on the delta-F and base values analysis look completely different, whereas the temperature coefficients of the total field difference almost coincide (Table 2). Correcting base values' estimations of H and Z components drifts by those obtained from the dF estimations, we found that the residual drifts (Column "Difference" in Table 2) could be very well explained by the sensor tilt. The possible sensor tilt is in contradiction with our expectation that the suspended sensor has to have very good vertical orientation and compensate pillar tilts. The further study is necessary to carry out for clarifying this behaviour.

CONCLUSIONS

The analysis of the temperature characteristics of the 1-second variometer LEMI-025, deployed in the upgraded observatory Icheon, South Korea, was carried out. The two complementary approaches – delta-F and base values analysis – were used. The latter allows us to determine the components' temperature coefficients, whereas the first of them effectively detects contributions to total field difference during the time intervals of absolute measurements. The considerable different effects of the sensor and electronics temperature variations was used to separate the temperature coefficients of the sensor head and the console. The significant non-linearity of the temperature dependencies, especially for the console, was revealed. The dF values after correcting temperature drifts do not exceed ± 0.5 nT during about one year.

The observed peculiarities of the console temperature characteristic is in good agreement with the laboratory tests of the temperature behaviour of the voltage reference used to form the bias fields along H and Z components. This fact gives us background to consider the voltage reference instability as a common source of the H and Z components' drifts due to the electronics temperature variations. We also supposed, that the sensor compensation windings, creating the bias fields, have equal temperature coefficients. Taking into account these assumptions, the temperature coefficients for total field difference, estimated by the delta-F method, were decomposed to estimate the coefficients of each sensor in proportion to the intensity of H and Z components. The comparison of delta-F and base value estimation reveal good agreement for the electronics temperature coefficients. The sensor temperature coefficients for components H and Z, estimated by the both methods, are significantly different. However, this difference could be explained by the sensor tilt. The reasons of the possible tilt of the suspended sensor need to be carefully studied in future. Obtained estimations of the temperature characteristics could be used for the correcting variometer data, but, due to the limited capabilities of such correction, it is recommended to consider possibility to stabilize the temperature of the instrument, especially its electronic unit. Using a temperature stabilized environment is the best way to reach very accurate measurements.

REFERENCES

Csontos A., L. Hegymegi, B. Heilig, 2007. 'Temperature Tests on Modern Magnetometers', Publs. Inst. Geophys. Pol.. Acad. Sc. C-99 (398) 171-177.

Intermagnet Technical Reference Manual, Version 4.6 2012. Edited by: Benoît St-Louis, 2012 http://www.intermagnet.org/publications/intermag_4-6.pdf.