EXPERIENCE OF OBSERVATORY PRACTICE WITH LEMI-004 MAGNETOMETERS

Valery Korepanov[1], Adolf Best[2], Bohdan Bondaruk[1], Hans-Joachim Linthe[2],Janusz Marianiuk[3], Kari Pajunpaa[4], Leonid Rakhlin[1], Jan Reda[3]

[1] *Lviv Centre of Institute of Space Research, Lviv, Ukraine;*
[2] *GFZ Potsdam, Niemegk Observatory, Germany;*
[3] *Geophysical Institute of Polish Academy of Sciences, Belsk Observatory, Poland*;
[4] *Finnish Metrological Institute, Nurmijarvi Observatory, Roykka, Finland.*

The perfectioning of flux-gate magnetometers (FGM) parameters is going so fast that now they practically eliminate all other types of magnetometers from applications where precise measurements of weak DC magnetic field components are necessary. Especially it is so in geophysics for land and observatory survey of Earth's magnetic field. Such outstanding parameters as long-term drift about 1-2 nT per year and noise level about 1-2 pT are reported together with practically absent temperature drift.

Certainly, few words said by the way in (Freja Team, 1994) about "zero offset stability is better than ±0,1 nT over a temperature range of ±60°C and for periods exceeding one year, ... the fluxgate sensor noise ~10^{-7} nT^2 Hz^{-1}" make big impression at all skillful in the magnetometry. Unfortunately, the attempts failed to find other paper of any of the authors of this work with more detailed explanations of with what testing facilities and in which conditions were obtained these figures and whether these results were confirmed by independent investigators.

But the aim of this paper is not to discuss these results. We want to exchange the experience of observatory tests of newly developed model of LEMI-004 magnetometer which showed the realistic level of main FGM parameters. About 20 pieces of this type magnetometers were manufactured and no special choice of tested specimen was made.

The work was done in frames of collaboration agreement between the European Geomagnetic observatories Belsk, Niemegk and Nurmijarvi from one side and Lviv Center of Institute of Space Research (LCISR) from another one.

The main idea of the development of new FGM magnetometers was to unite well-known and practically approved electronic circuit design with last achievements of microelectronics and material science. The additional conditions of the development were not to reach the record level, but good repeatability of parameters in the production and as low price as possible. Also the attention was paid to create convenient in the operation magnetometer, quickly adjustable to any place where observations have to be made, with wide potential application area.

The FGM circuit was developed on the base of long-term former experience of design, calibration and field and observatory use. Main peculiarities of the basic version are already described in details (Berkman et al., 1997), here only the obtained LEMI-004 technical specifications are given in the table below.

Table 1

Full measuring range:	±120000 nT
Measuring range of variations at analog output:	±5000 nT
Readings range at display:	±2000 or ±20000 nT
Resolution at display:	0.1 or 1 nT
Resolution at RS-232 digital output	0.1 nT
Noise level in the frequency band 0.01 -1 Hz, rms	<20 pT
Transformation factor of analog output:	2 mV/nT
Bandwidth of analog output:	DC-10 Hz or DC-1 Hz
Orthogonality error:	<30 min of arc
Step offset ranging band by each axis:	±9×10000 nT and ±9×1000 nT
Smooth offset ranging band by each axis:	1000 nT
Operating temperature range:	-20 to 40°C
Temperature drift	≤0.1 nT/°C
Temporal drift	≤±5 nT/year
Power supply, battery	12 V, 0.25 A
Weight: sensor with the support electronics unit	 1.7 kg 3.5 kg
Length of the connecting cable:	from 5 to 45 m

If to range the FGM parameters by their importance for geophysical need, the sequence will be following: long-term stability, noise level and temperature drift. All other FGM parameters are quite acceptable practically for any application and can be determined by certification.

Both long-term stability and noise level are physically the same noise parameters, but in different time domains. In order to have the full impression about temporal noise dependence of the FGM following temporal band share was introduced:

0,1 s - 100 s - flicker noise (f-band);

1 m - 100 m - short-term noise (s-band);

1 h - 30 days - mean-term noise (m-band);

1 day - 365 days - long-term noise (l-band).

Such division of time bands is not arbitrary. It is connected with different possible application area of FGMs. So, f-band noise allows to estimate the FGM applicability for magnetic pulsation study. Also the methodology of noise investigations in this band differs from the same in other bands. S-band noise is interesting for the application of FGM for mineral deposits prospecting. M-band is the time periods used for magnetotelluric investigations. And last but not least l-band noise is very important for observatory practice and it determines especially the necessary periodicity of absolute measurements. In all these bands the FGM noise was tested.

The special laboratory equipment developed and installed in LCISR allows to make detailed noise power tests in f-band. The typical time dependence of LEMI-004 noise power spectrum is shown on Fig. 1. Very low value of corner frequency f_c and good noise uniformity at higher frequencies are clearly seen. These tests particularly prove that this magnetometer excellently suits for magnetic pulsation study, the frequencies of which are within f-band.

Both the s-band and m-band noises were tested at Belsk Observatory, the basic magnetometer of which is of torsion type (PSM). This type magnetometers are especially good in mentioned temporal bands because of inherently low level of suspended magnet own oscillations if the temperature of the environment is strictly stabilized. In Belsk Observatory the temperature in reference magnetometer hut is maintained in the limits within ±0,1 centigrade. Fig. 2 illustrates the results of s-band tests. The resolution of registration unit was 30 pT/bit only and sampling was made once per second without averaging. Then the LEMI-004 s-band noise was estimated as the difference between output signals of X, Y, Z channels of LEMI and PSM. Special measures were taken in order to eliminate the time shift influence between the samplings of reference and tested magnetometers channels. The 10-minuts intervals were randomly chosen for tests in the day time when the activity of Earth's magnetic field was relatively low. It is well seen that the s-band noise is mainly within ±1 digit or about 50 pT.

The same methodology was used for m-band noise estimation. First the 30-seconds averaging of 1-second samples for each channel was made in the registration unit and then 2-minutes mean was constructed as one point at Fig. 3. The m-band noise for Z-component can be estimated as very good - about 0,3 nT/month. For X and Y components these numbers are about 1.2 nT/month and 0.5 nT/month respectively. But to this it is necessary to make following objections.

First, the tested LEMI-004 was placed outside of reference hut and no special pier and thermal stabilization was used.

Second, for the applied methodology of noise investigation very important is to have as good as possible alignment of sensor components of both reference and tested magnetometers. For Z-component it is possible to have always good alignment, but for X and Y axes to get the alignment error less than 30' is very difficult. As a result, in the plot for X-components difference we have a trend correlated with Y-component of magnetic field variations and in the plot for Y-components difference - correlated with X-component of the field, what is the main cause of bad results along X and Y axes.

The most complicated is the l-band noise investigation and not only because it needs very long time. In this time domain absolute measurements only can be the reference for noise calculation. In order to be as much sure in the obtained data as possible these tests were made with different specimens of LEMI-004 magnetometers in all involved in the collaboration Observatories. The test results are presented on Fig. 4.

Analyzing the results of l-band tests the objections to the precedent results obtained in Belsk Observatory also have to be taken into account. In Nurmijarvi Observatory both tested and reference magnetometers were in the same conditions. So it is possible to conclude that for all tested magnetometers randomly chosen the l-band noise was within INTERMAGNET standards requirements, i.e., no more than ±5 nT/year. For the best of them this value was 2-3 times less.

Also the second factor - temperature influence - was investigated in details. The Nurmijarvi Observatory has special facilities allowing to execute the multi-cycles automatic temperature tests in magnetically clean conditions. The system and software developed allows to calculate temperature dependence both for sensor and electronics unit separately and for all equipment together.

For magnetometers with ordinary FS typical temperature dependence ranges in the limits from 0,05 to 0,25 nT per degree being always the greatest by D (Y) component. It proves that compensation field circuit is made appropriately (lowest drift by Z components) and only slight expansions of sensor housing material lead to the tiny movements of the FS core axis the influence of which is the most observable by D (Y) component.

To confirm this the last models of LEMI-004 FGM were equipped with sensors which housings were made from special thermocompensated sitall glass with negligible temperature expansion. The results of thermal tests of such sensors showed practically absent temperature dependence of FGM components (Fig.5).

Other metrological parameters of each LEMI-004 magnetometer are certified using reference coil system and corresponding electronics of the Nurmijarvi Observatory. The software available there allows to make automatic tests with good repeatability in short time.

In conclusion it is interesting to compare the list of parameters of ideal magnetometer compiled during the 1st Workshop on Magnetic Observatory Instruments (Ottawa, 1986) by a group of experts (Trigg, 1988). The results of the comparison of main of them with LEMI-004 parameters are given in Table 2.

Table 2

Parameter	Ideal magnetometer	LEMI-004
Dynamic range	>±3000 nT	±5000 nT without commutation ±120000 nT using incorporated switches
Resolution	0,1 nT	0,1 nT
Noise	0,03 nT	0,02 nT
Linearity	0,1%	0,02%
Passband	DC-1 Hz	DC-1(10) Hz
Axes orthogonality	±30’	±30’
Temperature coefficient	Head <0,1 nT/°C Console <0,1 nT/°C	Both <0,05 nT/°C
Temperature range	-20 to +50°C	-20 to +50°C
Stability	0,25 nT/mo	0,5 nT/mo and 5 nT/year
Power	<100 W	3.0 W
Cost	≤15 000 USD	6 500 USD

From these data it is possible to conclude that the presented FGM version has enough good set of parameters and may be recommended for any area of on-land applications. In the further development it seems to be reasonable to concentrate not on the improvement of the metrological parameters - as it is known, it could be made by considerably higher price - but on the rise of operation convenience conserving low price.

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