GEOMAGNETIC INSTRUMENTATION FOR REPEAT STATION SURVEY

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Abstract. Repeat station survey measurements are important geomagnetic data because they are widely used both for fundamental science (e. g., study of Earth's magnetic dynamo) and for applied purposes (e.g., declination charts for aviation safety). To execute repeat station surveys, normally three types of instruments are used: absolute scalar magnetometers, three-component vector variometers, and theodolite-mounted one-component magnetometers. The modern specifications of each magnetometer are described together with simplified fundamentals of their operation. The recommended set of such devices is given and possible further development of this type of instrumentation is discussed.

Keywords: repeat station, flux-gate magnetometer, Overhauser magnetometer, non-magnetic theodolite

1. Introduction

Observation of the Earth's magnetic field remains an important branch of scientific research. Moreover, the number of geomagnetic observatories continues to increases – both manned and especially unmanned ones. Observatory data are shared via international networks. INTERMAGNET works with stationary observatories; CANOPUS, IMAGE and some other networks are for unmanned observatories. The same trend is observed with repeat station surveys – more often they are executed by international teams, especially in regions close to state borders.

Repeat station data are obtained by national institutions that are responsible for magnetic surveys with a maximum interval of five years. These measurements are used to determine the so called secular variations

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J.L. Rasson and T. Delipetrov (eds.), Geomagnetics for Aeronautical Safety, 145–166.

of the Earth's magnetic field – the slow changes of direction and value of the field vector with time. The example (Figure 77), shows that these changes are big and they demonstrate the evolution of the magnetic dynamo in the core of the earth. Permanent magnetic observatories are the most accurate sources of secular variation information, but the present network of magnetic observatories does not adequately cover the globe. Repeat stations provide an important and cost-effective means of supplementing observatory data with the most valuable stations being those remote from observatories. Repeat station data have long been used for producing regional field models and charts.

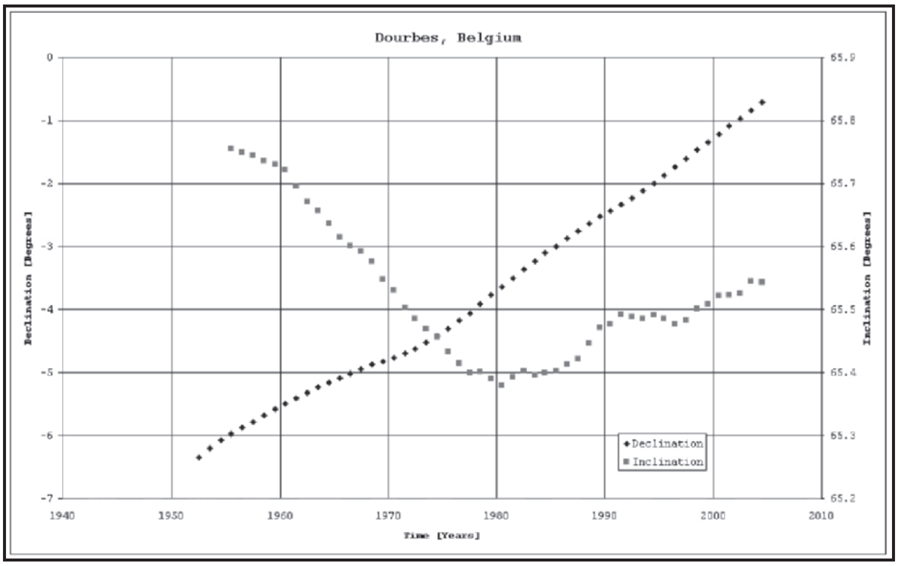


Figure 77. Declination and inclination changes at Dourbes magnetic observatory for 50 years.

Besides the fundamental scientific importance of the secular variations for understanding the Earth's magnetic dynamo mechanism, knowledge of the geomagnetic field elements (i.e. vector components) is of special interest for navigation in general and in particular for aircraft navigation.

The directions of geographic North (True North) and magnetic North do not coincide. The difference is the angle called "Magnetic Declination": to find True North by means of a compass, a correction should be introduced to the direction the compass indicates. Measurement of the declination is especially important at airports. Without information about the declination angle there is real danger that aircraft will have wrong headings when landing. Additionally, airports must provide adequate calibration pads for aircraft compass certification and checks (swings), where the magnetic declination should be precisely known. The magnetic compass is still the primary navigation device on aircraft. In case of failure of other electronic navigation devices (GPS, VOR) the magnetic compass is an important backup tool. The failure to correctly calibrate and operate magnetic compasses represents a security risk to aircraft and airports.

The knowledge of the geographical distribution of magnetic declination allows for the mathematical calculation of magnetic headings which also appear on aeronautical charts.

Declination is not a constant value, but changes rather chaotically due to secular variations of the geomagnetic field. In order to know the declination value precisely, regular magnetic measurements must be made. In the past, these measurements were made every 5 years, but now, most European airports require making such measurements once per year, for the sake of improving flight safety. This work is rather expensive, needs precise magnetic instrumentation, and takes qualified manpower. Additionally, there is no regular production of non-magnetic instrumentation for performing such measurements.

The aim of this paper is to analyze the state of geomagnetic instrumentation and to present recent developments in this field.

2. Requirements of the instrumentation

The key to obtaining useful repeat station data is the ability to make accurate corrections for transient field variations so that the secular variation can be determined from the differences between results from successive station occupations. These corrections can be obtained either by using one or more permanent observatories as a reference standard, or by installing a variometer on-site and running the repeat station as a temporary observatory.

Each method has its advantages and limitations. The reference observatory method is quicker, easier, and cheaper and is the natural choice when it can be demonstrated that the transient-field corrections obtained at the reference observatory are applicable at the repeat station site. It is important to investigate and confirm this result, and not simply assume it for convenience, before adopting the reference observatory method. Data from a local variometer help to determine the quiet level of the magnetic field when the repeat station is far from an observatory (Newitt et al., 1996). This is usually so when we apply the repeat station survey techniques for calibration pad certification at airports. A complete set of geomagnetic instrumentation must include three devices: an absolute magnetometer, a three-component variometer, and a theodolite-mounted declinometer-inclinometer. To satisfy the acceptable level of measurements error (~20" for declination and ~10" for inclination) the instrumentation has to fulfill necessary requirements to its metrological parameters. The main parameters are given in Table 12.

Table 12. Main requirements of the instrumentation for repeat station surveys.

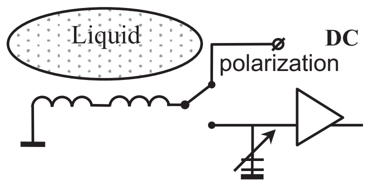
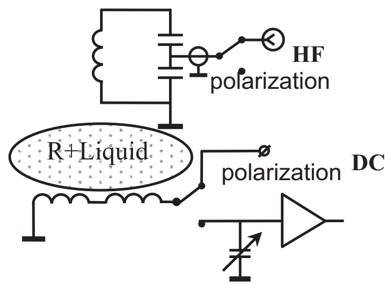
ABSOLUTE MAGNETOMETER	
Obligatory parameters	
Magnetic field measurement band	± 60 000 nT
Measurement resolution	0.1 nT
Absolute error of measurement	≤ 0.5 nT
Desirable parameters	
Stability of precessing liquid	≥ 5 year
THREE-COMPONENT VARIOMETER	
Obligatory parameters	
Magnetic field measurement band	± 60 000 nT
Measurement resolution	0.1 nT
Linearity	≤ 0.1 %
Temporal drift	± 2 nT/day
Thermal drift	≤ 0.2 nT/°C
Desirable parameters	
Power consumption	≤ 2 W
Sensor tilt compensation available	
DECLINOMETER-INCLINOMETER	
Obligatory parameters	
Magnetic field measurement band	± 1000 nT
Magnetometer offset	≤ ± 10 nT
Measurement resolution by field	0.1 nT
Measurement resolution by angle	1 arc sec
Desirable parameters	
Autonomous power supply	

Each of these instruments is described below in detail and some examples are given. Our goal was not to compare and criticize other available instruments – we used some known brands only to describe their specific peculiarities which could be interesting for the user.

3. Absolute magnetometers

The name “absolute” was given to the devices for measuring the magnetic field. The operation principle of these devices is based on fundamental physical constants. There are few known types of absolute magnetometers. The most common types are proton precession magnetometers. They are

Table 13. Principle of absolute magnetometer operation.

1	2
Schematics	
	
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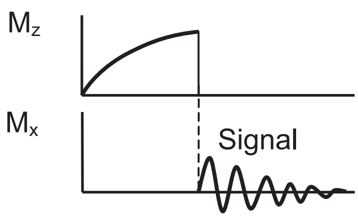	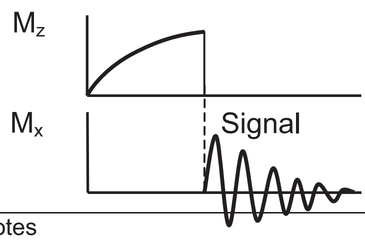
Notes	
Packard-Varian method Precession is stimulated by very rapid switch off. $H_P \approx 100 \div 300$ Oe	**Overhauser DC-HF polarization** Precession by switch off Radicals: Diphenyl-NO, stable, wide ESR line with easy saturation. $H_P \approx 15 \div 30$ Oe $H_{eff} = H_P * K_{OVH} \approx 2000 \div 3500$ Oe

used for measuring the magnetic field strength in the range of 20 μT to 100 μT with accuracy of 0.1nT. They are based on the Packard-Varian method where a proton-rich liquid (in the simplest case - water) is polarized by a strong magnetic field created with the help of a wire winding around this liquid volume, into which a DC current pulse is inserted (Table 13, item 1). After the pulse cessation, the free precession frequency, f, of protons can be observed and the formula:

$$2\pi f = \gamma'_p \, B$$

allows the measurement of the magnetic field module by way of the measurement of a frequency. The standard for the magnetic induction is thus conveniently converted to a frequency standard, which is widely available. The quantity γ'_p is the fundamental physical constant - proton gyromagnetic ratio.

Its recommended value, at low field for a spherical H_2O sample, at 25 degrees Celsius given by CODATA and adopted by IAGA in 1992 is (Cohen and Taylor, 1987):

$$\gamma'_p = 2.67515255\mathrm{T}^{-1}s^{-1}.$$

The magnetic sensor coil serves both to periodically apply a polarizing field to the liquid and to pick up the signal from the precessing protons after cutting off the polarizing field. An electronic console amplifies the precession signal and performs a frequency measurement with the required accuracy. This measurement is then scaled using γ'_p to give the field module intensity in Teslas. Such magnetometers mostly operate once per 5 seconds or less and their precision is often as high as 0.1 nT.

Modern proton magnetometers can be quite compact and have higher resolution and sampling rates. The Overhauser type magnetometer (Sapunov et al., 2001), in particular, is responsible for this progress and has the additional benefit of low power operation.

In addition, it applies an AC field in the radiofrequency band (Table 13, item 2) which allows it to get a much higher precession signal amplitude. One of the best magnetometers of this type is the POS-1 Overhauser magnetometer produced by Ural State Technical University (Russia) (Sapunov et al., 2001) shown in Figure 78.

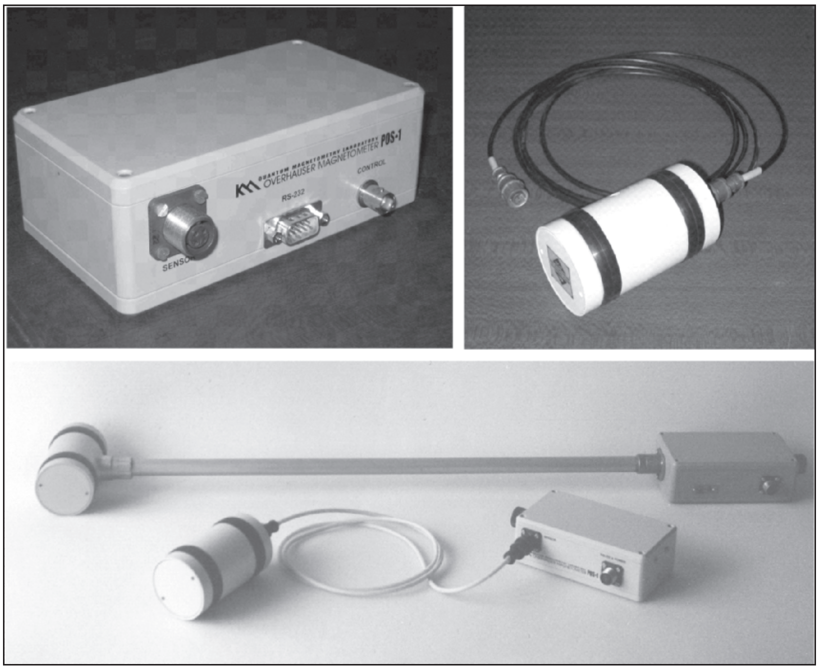

Figure 78. POS-1 Overhauser magnetometer.

The POS operation principle is similar to that of the standard proton magnetometer. Polarization by POS-1 Overhauser occurs in a bias DC-magnetic field (15-30 Oe strength) with an alternating HF-field (frequency about 55 MHz). In this way, it is possible to avoid a sharp decrease in the proton Overhauser signal in the range of 20000-40000 nT and to exclude systematic errors produced by the feedback circuit in other types of Overhauser magnetometers. This design uses a new stable chemical substance with lifetime of up to 10 years.

The POS digital processing of the proton precession signal (Denisov et al., 1999) ensures high sensitivity of measurements (up to 0.01 nT at a 3 sec cycling rate, or 0.1 nT at 1 sec. for the standard Overhauser head). The processing algorithm also provides simultaneous assessment of the measurement error by a quantity named QMC (quality of measuring conditions). QMC is a parameter of sensitivity estimate for the real measurement conditions in field units (nT) available for each single measurement.

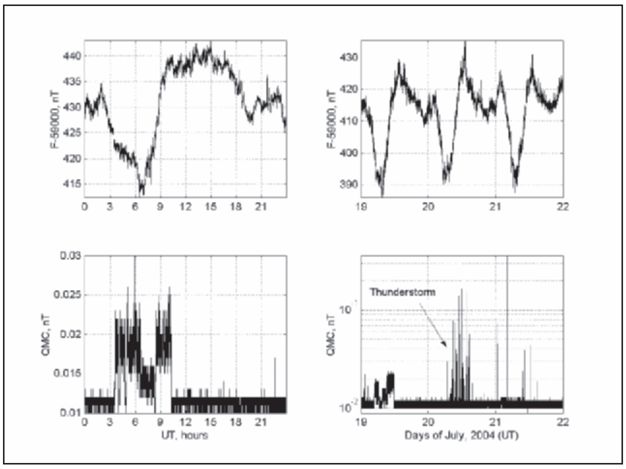

Figure 79. The records of POS-1 with QMC increase: because of technogenic noise (left panel) and thunderstorm (right panel).

The value of QMC is registered together with the total field and can be controlled visually by the magnetologist during processing. The usual QMC for POS-1 is about 10-12 pT. But it is also possible to see significant increases in QMC from time to time. The duration of these intervals vary, but changes correlate mostly with external factors. We assume that the origin of noise is technical. Figure 79 (left panel) shows POS-1 data with an increase of QMC during the daytime. The total field itself is not correlated with changes of QMC. The simultaneous measurements by two POS-1 showed that the increase of QMC is present in both records, and hence is not caused by sensor failure.

Not all noise appearing as changes of QMC is technogenic. It was noticed that QMC varied significantly during the passing of a thunderstorm close to the observatory (up to a few kilometers). The example of such an effect is shown on Figure 79 (right panel) – the thunderstorm moved near the observatory in the evening of July, 20 2004 (about 13UT). This meteorological event did not influence the total field.

An additional application of QMC for repeat station measurements may be the selection of the place for the installation of the POS sensor. The main technical specifications of the POS-1 magnetometer are given in Table 14 and its attributes and advantages are given in Table 15.

Table 14. Main technical specifications of POS-1 magnetometer.

Range of measurement	20000-100000nT
Resolution	0.001nT
Sensitivity (mean-square error at the optimal sensor orientation)	0.01 – 0.02nT at 3 sec (the best condition); 0.05 - 0.1nT at 1 sec cycle
Absolute accuracy	± 0.5nT
Gradient tolerance	up to 20000nT/meter
Operating modes	the user can select single or continued operation by commands via RS232 port
Reading intervals	1.0, 2.0 3.0 ... sec (optional 2, 3, 4, 5 Hz) in cycle mode
Data output	three wire RS232 port (binary and/or text format)
Power	10-15 VDC (15 VDC at 0,35 A max and 10 VDC up to 0,5 A max in polarization period)
Operating temperature	-10 to +60 C° (at -30 to +75 C° able to work)

Table 15. The attributes and advantages of POS-1 magnetometers.

POS-1 attributes	Possibilities
Stable sensor fluid with lifetime up to 10 years	Long use of magnetometer without re-filling sensor
Short time of sampling up to 1 s during continuous recording	Easy synchronization of variation measurements with POS-1 data
Small polarization current	Decrease the magnetic field disturbance from POS-1 (about 0.07 nT at 1.5 m) allowing location of the POS close to another sensor.
The digital connection of POS-1 and PC with cable length of up to 100 m	The recording system can be located a long distance from the sensor
Wide range of working temperature (down to -30°C)	Keeps recording during a long cut-off of the hut thermostatic system in the winter

POS-1 attributes	Possibilities
Small size and weight of POS-1 sensor head	Allows use of the POS-1 as the magnetic sensor of the component system
Parameter QMC	Allowing controls of the signal quality and noise level during the measurements

So, the parameters of this magnetometer fully correspond to necessary requirements. Additionally, it has a relatively low price. Therefore it is recommended for repeat survey practice.

4. Flux-gate magnetometers

Geomagnetic investigations need high accuracy data. Among various types of magnetometers, the flux-gate magnetometers (FGM) get high quality results at relatively low cost. They are the most widely used magnetometers for both observatory and repeat station observations of the Earth's magnetic field components. Recent developments in the technology, design, and manufacture of flux-gate sensors (FS) have enabled the sensors to operate within acceptable noise levels of a few pT. However, the sensors are especially sensitive to temperature changes and lack in long-term stability. These are important considerations for repeat stations surveys. To satisfy these temperature stability requirements, new theoretical and technological low cost approaches to the design of the FGM, were studied (Berkman et al., 1997).

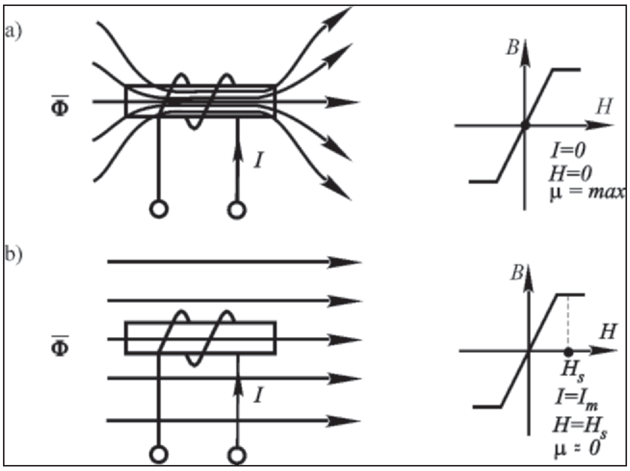

Figure 80. Principle of FGM operation.

In practice, FGMs are used for the measurement of the components of the stationary magnetic field vector. In repeat station survey applications, FGM's are used to measure the Earth's magnetic field vector. Their operation principle is based on Maxwell's law of electromagnetic induction which, in integral form can be written as

$$e = -\frac{d\Phi}{dt},$$

where *e* is the electromotive force (*emf*), Φ is the magnetic flux, and *t* is time.

According to this expression, only an alternating magnetic field can produce *emf* when intercepting a sensor coil. So, to measure a DC field it is necessary to modulate the DC magnetic field component in order to get an output signal. It works in the following way. The FGM sensor (FS) consists of a high-permeability, ferromagnetic core with a winding around it (Figure 80).

In the normal state of the ferromagnetic core, the magnetic field flux Φ is concentrated in the core (Figure 80, a), due to the cores high relative permeability,. If a strong current (*I)* is applied into the winding, the core becomes saturated and its relative permeability trends to unity. In this state, the core does not concentrate the magnetic flux (Figure 80, b). By introducing alternating current (*I)* into the winding (excitation current), it is possible to gate the magnetic flux Φ in and out of the core, or in other words, to modulate it, transforming from DC to AC flux. The AC flux, intercepting winding, generates *emf* at its output, according to Maxwell's law.

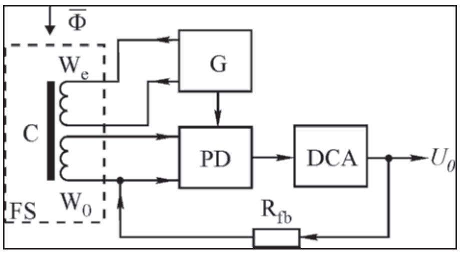

Figure 81. Simplified FGM operation diagram.

The simplified functional diagram of FGM is presented in Figure 81. The bar-type flux-gate sensor (FS) consists of a magnetic core C, an excitation winding $W_{e,}$ and an output/feedback winding W_0. The Oscillator/Drive unit (G) provides alternating current through the excitation winding W_e, which drives the magnetic core of the sensor in and out of saturation. In the moments of core saturation (two times per one period of excitation current) its relative magnetic permeability falls from a maximum value to 1. This leads to the modulation in the core twice for an excitation period of the total magnetic flux, produced by the external magnetic field. Total magnetic flux changes induce the output signal in the output coil W_0 of the sensor at the second and all even harmonics, which is dependent on both magnitude and polarity of the external field. The sensor (FS) output signal goes to the phase synchronous detector PD with a low-pass filter at the output. The PD uses the clock signal of excitation, double frequency signal, from the Oscillator/Drive circuit G and forms the output DC signal proportional to the amplitude and polarity of the measured magnetic field. The output signal of the PD is further amplified by the DC amplifier DCA and forms the FGM output signal U_0. To stabilize the transfer factor of the FGM, a feedback resistor R_{fb} is coupled between the FGM output and the W_0 winding. The DC current, through resistor $R_{fb,}$ creates C magnetic flux in the FS core. This compensates the measured flux Φ and stabilizes the total FGM transfer function.

The high quality FGMs use a ferroresonance excitation mode (FEM), when the excitation winding W_e of flux-gate core C is shunted by capacitance C_k and they both form a non-linear oscillator with low active losses (Berkman et al., 1997) (Figure 82). Figure 83 shows current and voltages in the circuit.

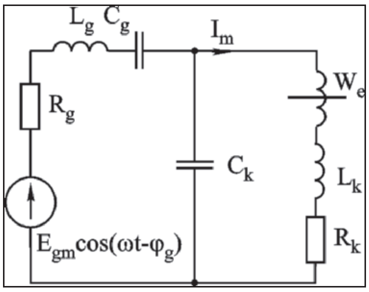

Figure 82. FEM schematic diagram.

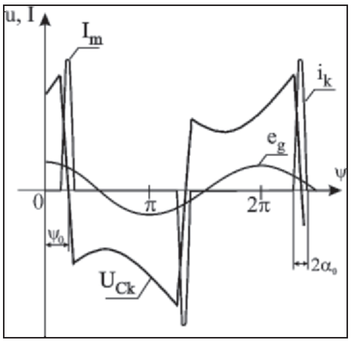

Figure 83. Voltage and current curves of FEM.

Here R_g , L_g , $C_{g,}$ and E_g are output parameters of the excitation current generator G. L_k and R_k are inductance and resistance of the winding W_e , φ – E_g describes the phase and $2\alpha_0$ is the excitation pulse width.

The series circuit $L_gC_gC_k$ in FEM is tuned near the frequency ω of the excitation source E_g. The main function of the FEM is to store capacitance

(C_k) charge which is created at the end of the demagnetization interval for the generation of the current discharge pulse (I_m). The pulse is of great amplitude at the saturation interval. Because of the relatively short time of the saturation interval, ($2\alpha_0 << \pi$), the energy input is sharply decreased, especially when the discharge circuit L_kC_k has a high Q- factor.

Using FEM, it is possible to have current pulses I_m (Figure 83) in the excitation winding achieving amperes, when mean consumed current is only tens of milliamperes and active losses in the winding are less than 0,05 watts. A high amplitude of the excitation field (2000 A/m and more) eliminates hysteresis zero drift, and its short duration lowers heat dissipation in the sensor volume. Additional advantages of the FEM are the sensitivity stability and low noise level: typical values are 20 pT rms, and the lowest values about 3 ÷ 5 pT.

A reference, three component flux-gate magnetometer LEMI-018 that uses this excitation mode was developed especially for measurements in difficult field conditions. Its external view is shown in Figure 84 and its technical parameters are given in the Table 16.

Figure 84. Three component flux-gate magnetometer LEMI-018.

Table 16. LEMI-018 main technical parameters.

Measurement range along each component	±65 000 nT
Resolution	10 pT

Noise level at analog output in the band 0.01 –0.5 Hz	< 10 pT
Long-term zero drift	< ± 5 nT/year
Temperature drift	< 0.2 nT/°C
Transformation factor linearity error	< 0.01%
Components orthogonality error	< 30 min of arc
Time of samples averaging	1, 2, 5, 10, 60 s
Internal FLASH-memory volume	512 MB
Operating temperature range	minus 20 to +40 °C
Power supply source	12 V
Power consumption	< 0.6 W
Weight:	
sensor with rotating basement	1,7 kg
electronic unit with built-in battery	4 kg
Length of connecting cable between sensor and electronic unit	7 m
Optional	memory volume and cable length extension

As was previously stated, in order to be suitable for repeat station surveys, the FGM has to have long term baseline stability and very low thermal drift. Both these parameters were investigated and the following results were obtained.

Figure 85 displays FGM thermal test data. Figure 85 a, shows the FGM baselines change with temperature for all three components. Even without compensation, the thermal drift for LEMI magnetometers fits in the limits ±0.2 nT/ºC. In some applications thermal drift values can be decreased further with specially designed drift compensation hardware or software. Results of the thermal dependence of baselines for a compensated FGM is shown in Figure 85 b. Thermal drift for a compensated FGM is negligible.

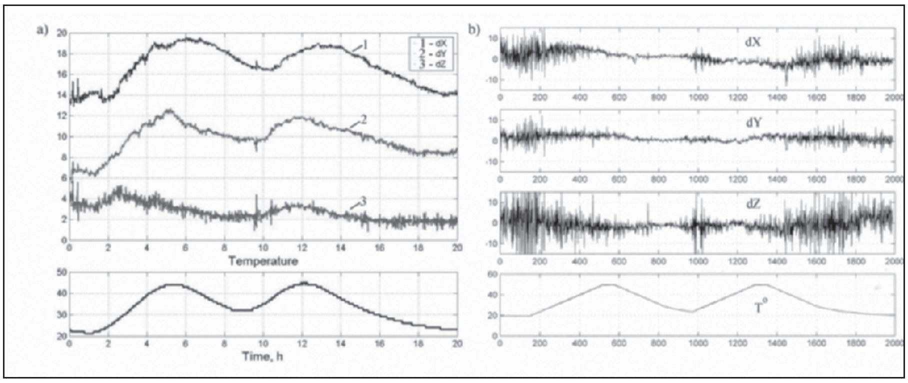

Figure 85. Thermal tests results.

The LEMI FGMs also demonstrate temporal stability. Figure 86 shows the results of absolute measurements of FGM LEMI-008 baselines for almost three years. It can be seen that this component of drift is well below the international standard of ± 5 nT per year.

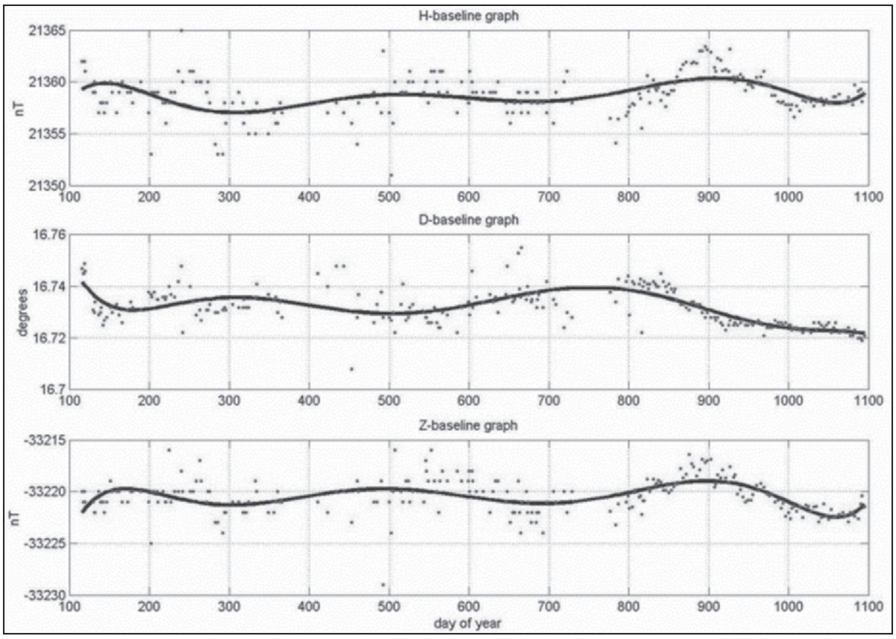

Figure 86. Long-term baseline stability.

In summary, because the FGM is highly accurate it is appropriate to use in field applications, for repeat station surveys, especially in regions with geomagnetic anomalies or sites far from geomagnetic observatories (~ more than 50-70 km).

5. Theodolite-mounted declinometer-inclinometer

The ultimate goal of repeat station survey work is to determine the absolute values of the Earth's magnetic field components. In practice, it is made on the basis of exact (absolute) measurement of the scalar value (modulus) F of the magnetic field with the help of an absolute magnetometer (see section 3) and measurements of the Earth's magnetic field, declination angle (D) and inclination angle (I). The declination angle (D) is the angle between the direction to geographic North (True North) and the direction to the geomagnetic North. The inclination angle (I) is the angle between the vector of the Earth's magnetic field and its horizontal component. Having declination (D), inclination (I), and F it is then easy to calculate the X, Y, Z components. Details of this procedure and minimizing measurement error are described in (Newitt, 1996).

The classic instrument used for D and I measurements is a portable one-component, flux-gate magnetometer. Its sensor is mounted on the telescope of a non-magnetic theodolite so that the sensors' magnetic axis and the telescope optical axis are parallel. The sensor is coupled to a battery-powered electronics unit by a long flexible cable. The instrument is commonly called a Declination-Inclination Magnetometer (DIM).

Before providing a detailed description of the DIM, it is necessary to mention that, starting from about 1960 (Alldredge, 1960) new instruments for absolute measurement of Earth's magnetic field were proposed. The majority of these devices measured a given component of the magnetic field using a scalar absolute magnetometer mounted in a three-component coil system where the other two magnetic field components are compensated with current in the windings. There were many attempts to build and commercialize such instruments. The most successful design the dIdD magnetometer (Pankratz et al., 1999). Recently a new device which uses both an absolute sensor with a field compensating coil and a theodolite has been designed. It is known as the DIMOVER (Sapunov et al., 2004). A comparative evaluation of the new devices with traditional methodology shows that they are not the quality of the DIM (Kotzé et al., 2004). Here only the DIM will be described.

The most widespread, accurate instrument in use at the end of the 20th century was the DIM, produced by Bartington in Great Britain. The single component fluxgate sensor is mounted on a Zeiss-Jena 010B non-magnetic optical theodolite, which has 1 second of arc resolution. The production of these theodolites was discontinued because of low market demand and now most theodolites are produced with electronic read-out and have magnetic components. These are more accurate and easier to use than optical theodolites, but they can not easily be demagnetized. Today the only 1-second, steel, optical theodolite on the market is the 3T2KP, produced by the Ural Optical-Mechanical Factory (UOMZ) in Ekaterinburg, Russia. These theodolites have nearly the same construction and specifications as the Zeiss-Jena 010B and attempts to demagnetize them were successful. Lviv Centre of Institute of Space Research (LCISR), Ukraine, and Mingeo Company, Hungary, now produce DIMs based on this demagnetized theodolite.

The 1-second resolution, demagnetized theodolite, 3T2KP-NM has technical specifications similar to those of Zeiss-Jena 010B (see Table 17 below).

Table 17. Main parameters of 3T2KP-NM theodolite.

Measuring accuracy face left/face right	2"
The same for zenith angles (mz)	2.4"
Measuring range for zenith angles	30-145°
Telescope	
Image position	erect and true-to-side
Magnification	30×
Angle of field of vision	1°35'
Shortest sighting distance	1.5 m
Stadia factor	100±05
Addition constant for stadia factor	0
Vertical index stabilization	
Operating range of the pendulum	±3′
Mean square setting error	0.8"
Plate levels	
Tubular level angular value	15"/division
Circular level angular value	5'/division
Graduated circles	
Horizontal/vertical circle dial diameter	90 mm
Coarse finder scale division value	10°
Circle scale division value	10'
Micrometer scale division value	1"
Built-in optical plummet	
Image position	erect and true-to-side
Magnification	2.5×
Angle of field of vision	4°30'
Focusing range	0.6 m to infinity
Weight (kg)	
Instrument	4.0
Support	0.7
Instrument in plastic container with accessories	9.2
Tripod	5.6
Dimensions (cm)	
Height of instrument with support	34.5
Height of horizontal axis from the lower support	
plain with footscrews in middle position	23.2
Container	47×24×21
Tripod	d16 x (100-160)
Operating temperatures	-10 - +50° C

The demagnetization of the theodolite is a complicated process because it is impossible to predict which parts of the theodolite will be from magnetic material. The possible influence of remanent magnetization on the D and I measurement precision was studied in depth. The results of Rasson's study (Rasson, 1994) show that the remanent magnetization of telescope parts has little or no influence on the measurements (see Table 18 and Table 19 from (Rasson, 1994)).

Table 18. VFO31 variometer declination baseline.

D_0	ε (”)	δ (”)	S_0 (nT)	Conditions	Orientation	Location
2°52’03”	-12	53	-1.9	no magnet		
2°52’17”	-42	50	558	magnet	horizontal	on telescope
2°51’54”	-8	63	-1940	magnet	vertical	on telescope
2°51’56”	-7	55	-2.2	no magnet		
2°52’01”	-8	53	-2.4	magnet	horizontal	on alidade
2°52’06”	-2	787	-28	magnet	vertical	on alidade
2°52’00”	-1	56	-2.2	no magnet		

Table 19. VFO31 variometer horizontal and vertical component baselines.

H_0	Z_0	S_0 (nT)	δ (”)	Conditions	Orientation	Location
20880.4	42176.9	-2.2	54	no magnet		
20880.7	42177.0	929	55	magnet	horizontal	on telescope
20880.7	42177.0	-2114	65	magnet	vertical	on telescope
20880.0	42177.1	-2.2	51	no magnet		
20908.5	42163.0	-4	-2419	magnet	horizontal	on alidade
20632.2	42299.1	-0.3	-271	magnet	vertical	on alidade
20880.3	42176.9	-1.6	53	no magnet		

These results were encouraging and it was concluded that no special attention should be paid to the demagnetization of such a complicated component as the telescope. The influence of the remanent magnetization on the most important part of the theodolite, the theodolite main shaft, which determines the theodolite precision, was tested. The acceptable magnetic cleanliness limits were determined to be below 10 nT at 5 cm distance from the shaft axis (see the results given in Table 20).

Table 20. Shaft magnetism influence.

	X, nT	Y, nT	Z, nT
Slightly magnetic shaft	18860,0	1465,5	46024,3
Non-magnetic shaft	18862,4	1466,1	46023,2
Belsk observatory bases	18862,5	1466,5	46023,5

LCISR continues its production line of LEMI type magnetometers with the LEMI-203 instrument (LCISR, 2005) and their comparative tests with Bartington and DIM-France instruments showed the same levels of precision of D and I measurements (Pajunpaa et al., 2001).

The LEMI-203 magnetometer sensor housing can be mounted on both Zeiss-010 and 3T2KP-NM non-magnetic theodolites (Figure 87).

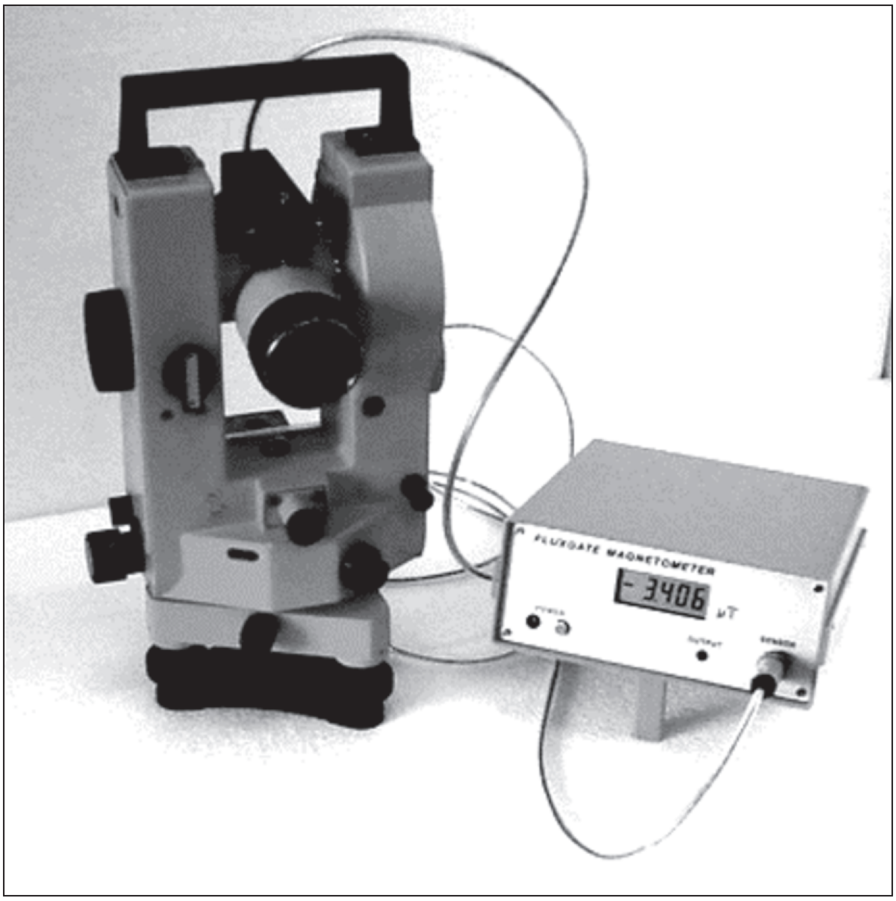

Figure 87. LEMI-203 DIM.

The sensor is coupled with the electronic unit by a flexible cable. The main technical parameters of LEMI-203 DIM are given in Table 21.

Table 21. Main technical parameters of LEMI-203.

Three measuring ranges, switched automatically:	
Range I	± 70.00 mcT
Range II	± 20.000 mcT

Range III	± 2.0000 mcT
Resolution at each range: Range I Range II Range II	 10 nT 1.0 nT 0.1 nT
Analog output transformation factor	0.05 mV/nT
Frequency bandwidth of analog output	DC-10 Hz
Output resistance	≤100 Ohm
Analog output noise in the frequency band 0.03 - 1 Hz	< 20 pT rms
Operating temperature range	minus 5 to +40°C
Internal power supply, battery	12 V, 1,2 Ah
Weight: sensor with support electronic unit with battery	 0.2 kg 2.5 kg
Dimensions: sensor with support electronic unit with battery	 27x27x75 mm 174x78x200 mm
Length of connecting cable	4,5 m

The simplified functional diagram of the LEMI-203 single-axis magnetometer is shown in Figure 81. The LEMI-203 can be used conveniently both in the observatory and in field conditions. The sensor is fixed to the theodolite's telescope so that sensor's magnetic axis and the telescope's optical axis are parallel. The sensor's magnetic axis alignment at Bartington is made only by them and is very costly. The LEMI-203 sensor has a user friendly design (Figure 88). Alignment can be made by any qualified user following a simple procedure described in the manual (LCISR, 2005).

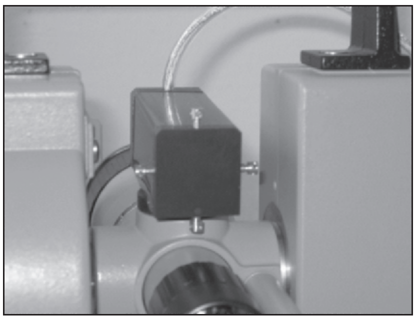

Figure 88. LEMI-203 sensor construction.

At the XIth IAGA Workshop on geomagnetic observatory instruments, data acquisition and processing (Japan, November 9-17, 2004) the comparative tests of 19 DIM instruments took place. In spite of a magnetically disturbed time, all four LEMI-203 instruments taking part in the comparative measurements showed high levels of accuracy (Masami, 2004).

6. Conclusion

Geomagnetic instrumentation used in repeat station surveys was described. Recent interest in field surveys has been driven by the need to study secular variation and the practical need to calibrate airport swing bases. This has promoted the development of a new generation of instrumentation. New technology allows a united instrumentation set and user's software for repeat station surveys (Figure 89), instead of the commonly used set of separate devices from different manufacturers. A complete instrument and software set has been developed at LCISR (LCISR, 2005). LCISR has great experience in theoretical, technological, and experimental studies and they propose their instrument set as a cost-effective and user-friendly solution for repeat station and airport swing base surveys.

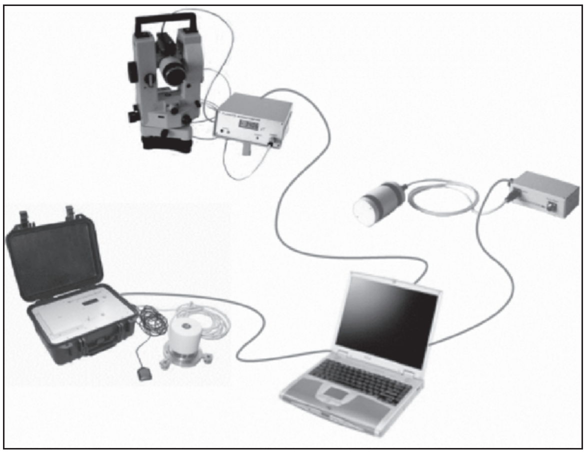

Figure 89. Advanced instrumentation set for repeat station survey.

Further progress in the creation of such instrumentation can be expected in the future, both in the improvement of parameters of the traditional DIM, variometer, absolute magnetometer set and in the creation of new technologies based on absolute magnetometer applications.

Acknowledgements

The support of Dr. Jean Rasson, the head of Dourbes Geomagnetic Observatory, without which this paper would never appear, is highly appreciated.

References

Alldredge L. R., 1960, A proposed automatic standard magnetic observatory, Journ. Geophys. Res., 65, 3777-2786.

Berkman R., B. Bondaruk, V. Korepanov, 1997, Advanced flux-gate magnetometer with low drift, *XIV IMEKO Word Congress. New measurements - challenges and visions,* Tampere, Finland, , Vol. IVA, Topic 4, pp. 121-126.

Cohen E. R. and Taylor B. N., 1987. The 1986 CODATA recommended values of the fundamental physical constants. Journal of Research of the National Bureau of Standards (U.S.), 92, 85-95.

Denisov A., Sapunov V. and Dikusar, 1999 Calculation of the error in the measurements of a digital-processor nuclear-precession magnetometer, Geomagnetism and aeronomy, 39, 68-73.

Kotzé P. B., L. Loubser, H. Theron, 2004, Comparative evaluation of a suspended dIdD, an unsuspended dIdD, and a FGE fluxgate system, Proceedings of the XIth IAGA Workshop on geomagnetic observatory instruments, data acquisition and processing (Kakioka and Tsukuba, Japan, November 9-17, 2004), 176-180.

LCISR (2003); http://www.isr.lviv.ua.

Masami O., 2004, Intercomparisons and tests of geomagnetic instruments and measurement training at the Kakioka Magnetic Observatory, Japan, in 2004, Proceedings of the XIth IAGA Workshop on geomagnetic observatory instruments, data acquisition and processing (Kakioka and Tsukuba, Japan, November 9-17, 2004), 6-23.

Newitt L. R., C. E. Barton and J. Bittely, 1996, Guide for magnetic repeat station surveys, Published by IAGA, J. A. Joselyn, Boulder, USA.

Pajunpaa K., J. Bitterly, H.-J. Linthe, V. Korepanov, 2001, Absolute measurements: comparative study of instrumentation, Contributions to Geophysics and Geodesy, Vol. 31/1, 131-136.

Pankratz L. W., Sauter E. A., Körmendi A., Hegymegi L., 1999, The US-Hungarian delta I – delta D (DIDD) quasi-absolute spherical coil system. Its history, evolution and future, Geophysical Transactions, 42, 195-202.

Rasson J., Progress in the design of an automatic DIflux, 1994, Timetable and abstracts for the Lectures Session of Geomagnetic Observatories Instruments, Data Acquisition and Processing, Dourbes, Belgium, September 18-24.

Sapunov V., Denisov A., Denisova O. and Saveliev D., 2001. Proton and Overhauser magnetometers metrology. Contributions to Geophysics & Geodesy, 31, 119-124.

Sapunov V., Denisov A. et al., 2004, Theodolite-borne vector overhauser magnetometer: DIMOVER, Proceedings of the XIth IAGA Workshop on geomagnetic observatory instruments, data acquisition and processing (Kakioka and Tsukuba, Japan, November 9-17, 2004), 159-164.

DISCUSSION

Question (Spomenko J. Mihajlovic): What does it mean compensation for thermal drift?

Answer (Valery Korepanov): This means that the thermal drift has to be calibrated first, i.e., the zero shift for given temperature change has to be determined during thermal tests and then you have possibility to compensate the drift, because all our magnetometers have the measurement of the temperature and the compensation may be made automatically or during data processing, using thermal factor and value of temperature change.

Question (Angelo De Santis): I believe that the future of magnetic monitoring in seismic and/or volcanic areas will see the use of vector magnetometers.

Do you think that this can be reached in a nearby future with your instruments?

Answer (Valery Korepanov): Yes, because one of the major problems of component magnetometers – too big temporal and thermal drifts – has already been solved. Some of the models of our magnetometers, e.g., LEMI-018 with special calibration, may have resulting temporal drift below +- 3 nT per month and thermal drift below 0.1 nT per centigrade, what is very close to scalar sensors.

Question (J. Miquel Torta): Can the temperature effect be compensated with your observatory variometer even if the variation hut has no temperature control?

Answer (Valery Korepanov): Yes. But the magnetometer has to be specially prepared, i.e., thermal drift has to be calibrated first, and then you have the possibility to compensate it. All our magnetometers also measure the ambient temperature. The temperature effect compensation may be made automatically or later during data processing, using the calibrated thermal factor and value of temperature change.