50 years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part I, Geology and Geophysics, Sofia, 2003, pp.373-377

IMPROVEMENTS AND INNOVATIONS IN REGISTERING THE GEOMAGNETIC FIELD PARAMETERS

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ABSTRACT
The paper discusses the improvements and innovations made in the classical registration of the geomagnetic field (GMF). Complex equipment for automatic measurement and registration of the GMF horizontal component and automatic digital registration of the four basic parameters of that field – declination D, horizontal intensity H, vertical intensity Z and total vector F is considered. The shortcomings of the classical analog photographic registration used until now and the positive effect of implementing the new methods and equipment are manifested. Some of these are being used at the Panagyurishte Geomagnetic Observatory of the Geophysical Institute of the Bulgarian Academy of Sciences and others are to be introduced there as well. The methods and equipment have been patented.

At present tens of geomagnetic observatories round the world use the classical methods and equipment for analog photographic registration of the geomagnetic field parameters (Gauss, 1952; Penkevich, 1948). These include a number of manual test operations requiring a long time without providing the same conditions for the various experiments and allowing for high probability of errors. The data obtained from these tests are not suitable for direct computer processing or transmission through a telemetric channel.

Complex equipment for measuring the absolute value of the GMF horizontal component H_T and automatic digital registration of the basic parameters of that field has been developed to eliminate these shortcomings and in particular, to increase considerably the accuracy, cur down a number of labour-consuming manual operations, reduce practically to zero the time required to obtain the results, automate the measuring and calculating process as well as perform some additional functions.

1. COMPLEX EQUIPMENT FOR MEASURING THE GMF HORIZONTAL COMPONENT

Complex equipment for measuring the GMF horizontal component was proposed and designed. A basic unit in the complex equipment is the precise periodometer. Such a precise periodometer – PPM-MO (Mardirossian et al, 1988) was designed especially for implementation at the Panagyurishte Geomagnetic Observatory (GMO).

Fig. 1 illustrates schematically the PPM-MO operation. The light beam from collimator 2, reflected from the mirror-polished part of the oscillating permanent reference magnet 3, is periodically incident on the photo conversion unit (PCU) mounted on the zero line where the beam velocity is maximum - V_{max}. This ensures minimum error in reading the times between each beam incidence on the PCU. The electric signal generated during each beam incidence is transmitted to the PPM-MO.

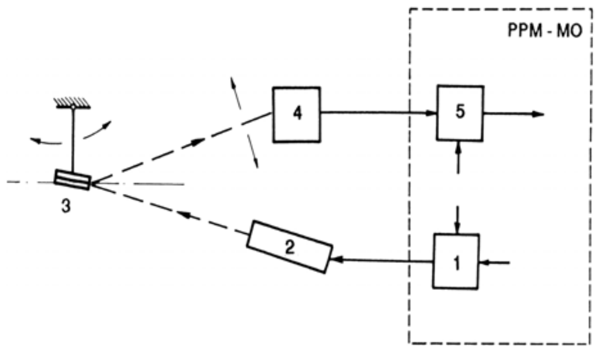

Figure 1.

The method and implementation were patented (Mardirossian, Fratev, 1989) and the main PPM-MO design-performance characteristics are given in Mardirossian et al (1988).

Since the permanent reference magnet oscillates not in vacuum but in a real air environment, minimum error and maximum reliability in comparing the individual measurements can be obtained for all these measurements only if it is possible to make sure that they are performed under magnet oscillations of equal amplitude. However, this cannot be controlled by the visual method used so far.

In Penkevich (1946) for the value of the difference between the oscillation periods with and without attenuation we have $\Delta T \approx 0.00006$, i.e. the influence occurs in the 4th or 5th decimal place. If until now it was negligible given the methods and equipment that registered the period T to an accuracy of up to three decimal places, with the introduction of the new methodology and equipment capable of reading within an accuracy of up to six decimal places, this negligence is now considered incorrect.

Methods have been created to control automatically within high accuracy the oscillation amplitudes *a* of the magnet and the amplitudes A_i of the light spot reflected by it during the measuring process, respectively. After initial oscillation of the magnet, an optoelectronic circuit traces the oscillation amplitudes and upon reaching the assumed initial (maximum) value A_{max}, it switches on the PPM-MO. Upon reaching the determined finite (minimum) value A_{min} the device is switched off.

The implementation of the proposed method is based on a model TSL-215 opto sensor with an amplitude resolution of 0.125 mm, i.e. the angle can be controlled within an accuracy of the order of 0.5^0. Thus amplitudes A_i corresponding to the measured periods T_i, are entered directly in the computer. In addition, it is possible to control to what extent the deviation amplitudes on both sides of the meridian are similar thereby judging about the mechanical parameters of the oscillation system.

A digital signal is transmitted to the computer by an EW (east-west oriented) seismometer mounted in the basement of the Panagyurishte GMO. It is possible to analyse and search for a correlation of inaccuracies between the individual measured periods and the microseismic vibrations. When such a correlation is established, the measurement (or reading of already measured periods) is carried out only at a microseismic noise level lower than the determined threshold level for non-discredited measurements. For the particular case the lab has assumed a threshold of $2A_{MN} \leq 0.05$ mm in the frequency domain 0.3 Nz $\leq f \leq$ 60 Hz.

Fig. 2 shows a block diagram of the complex equipment for measuring the GMF horizontal component. The respective units are 1 – periodometer, 2 – amplitude control unit, 3 – hygrometer, 4 – thermometer, 5 – seismometer, 6 – computer.

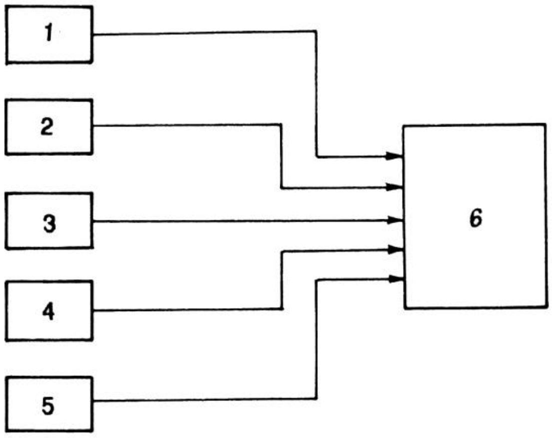

Figure 2.

As it is normal to expect, the increase in the equipment accuracy by two orders raised some methodological problems. In the first place, it is the fluctuation of the 4th decimal place where a unit equals approximately 10 *nT*. It was necessary to give an answer to the question of what this fluctuation, reaching up to one to three units in the 4th decimal place, is due to. The problem is essential because it is known that the accuracy of the other GMF elements depends on the accuracy of determining the horizontal intensity *H* (Cholakov, 1989).

The main external disturbing and interfering factor in the high accuracy measurements is the change in the geophysical parameters, in this particular case the humidity, temperature, atmospheric pressure and microseismic vibrations. At stationary observatories like the Panagyurishte GMO it is normal that measures should have been taken to minimise their impact. The effect of these measures is different for the different geophysical factors but their complete avoidance is practically impossible.

The effects of external and internal factors are divided conditionally and considered separately. The external factors are temperature, humidity and atmospheric pressure. The experiments performed to cause artificial changes in the temperature and humidity showed that such changes would not affect the values of period *T* at least up to the 4th decimal place. Similarly, it is shown that the atmospheric pressure variations reaching up to approx. 10hPa/3 h have no effect on the accuracy of measurement.

The effect of the microseismic vibrations on the accuracy of measuring the absolute value of the GMF horizontal component *H* was studied. The microseismic vibrations within the frequency range of 3-4 to 50-60 Hz are most strongly expressed and commonly have maximum amplitudes of several to several tens of μm. These short-period vibrations of the Earth's surface in relation to the permanent magnet oscillations can affect both the instantaneous spatial position of the collimator (C), magnet (M) and photo sensor (PS) and directly the permanent magnet oscillations. The analysis of all possible situations, bearing in mind the amplitudes, frequency and phase characteristics of the microseismic noise as well as the mass and elastic parameters of resonance frequencies of the mechanical elements of the complex equipment is very complicated. Therefore, we restricted our analysis only to considering the two simplified boundary cases:

a) The instantaneous vibration of the collimator C and photo sensor PS (units 2 and 4 in Fig. 1, respectively) is synchronous and co-phase.

b) The instantaneous vibration of C and PS is in antiphase.

The second case has practically a very low degree of probability as the collimator and the photo sensors are mounted on a common foundation. For the assumed mean value of the amplitudes of the microseismic vibrations of the order of 1.0 μm and for the most unsuitable instantaneous position of the collimator and photo sensor, the maximum error in measuring the period T_x can be of the order of $10^{-5} - 10^{-6}$, i.e. in the 5th and 6th decimal place of the results obtained.

Of special interest is the error obtained from possible changes in the luminance, focusing, geometry and spectral composition of the light beam incident on the PS during the measuring process. Eventually, the change in these parameters can sooner or later lead to illumination, and consequently, actuation of the PS thus causing readings of shorter or longer periods than the actual ones T_x. Bearing in mind the invariable state of the optical details it was found that possible variations of the current in the collimators of the order of $\Delta I \approx 2 \div 3$ mA can cause a change in the luminance of the order of $\Delta B \approx 0{,}3$ mW/m^2 (Mardirossian, 1999), which could not give rise to luminance, geometric and spectral changes in the beam incident on the PS that can have a relevant influence on the accuracy of measuring the period T_x.

With the aim of checking in situ the theoretical assessments of effect of the microseismic vibrations on the accuracy of measuring the GMF horizontal component, a real experiment was conducted at the Panagyurishte GMO. Simultaneously with measuring T_x, were measured the three components (displacement x, velocity $\dot{x}$ and acceleration $\ddot{x}$) of the horizontal microseismic movements of the foundation on which the oscillating system of the permanent reference magnet is mounted. The processing and analysis of the results obtained shows that there is no correlation between the maximum fluctuations of T_x and the amplitudes of the microseismic vibrations. Furthermore, it was found that in the range of 0,3 ÷ 0,4 Hz, corresponding to the natural periods of oscillation of the two reference magnets there are not seismic vibrations with amplitudes exceeding the average amplitude for the entire studied spectrum. A similar conclusion can be drawn about the range of the third harmonics (0.9 ÷ 12 Hz). Therefore, the vibrations of the foundation on which the permanent reference magnets are mounted, caused by the local microseisms do not introduce changes in the measured periods T_x within the measurement error.

The analysis of the telemetric registration at the National Operative Telemetric System for Seismological Data (NOTSSD) (Samardjiev et al, 1980) for the period April 1998 to August 1999, obtained by the vertical seismometer S-13 (Operation and..., 1989) mounted in the basement of the Panagyurishte GMO at a distance of 20 m from the horizontal intensity *H* measuring equipment did not show any presence of macroseismic events or an anomalous high level of microseismic noise during these measurements.

The nearly 10-year operation of the complex equipment for measuring the GMF horizontal component enabled us to obtain the following relevant results and make the respective conclusions (Mardirossian, 2001):
- the accuracy of the results obtained increased by at least two orders;
- the time for obtaining the result is practically zero;
- obtaining the value of T_x directly in a digital form allows for its further automated primary processing, registration by modern methods, telemetric transmission, etc.

There are technical and technological reserves (better circuit technique, more reliable electronic components, increasing the optical arm of the light beam, using a differential PS, etc.), which, if realised, can lead to increasing the accuracy of measurement by at least one more order. This can be done naturally if such accuracy is considered to be necessary and applicable in the geomagnetic theory and practice including studies on anomalous and disastrous natural phenomena and processes.

2. DIGITAL REGISTRATION OF THE GEOMAGNETIC FIELD PARAMETERS

A method has been developed for automatic digital registration of the four basic GMF parameters – declination *D*, horizontal intensity *H*, vertical intensity *Z* and total vector *F*. It consists in using part of the light beams by which the analog photo registration is accomplished to obtain a digital electric signal corresponding to that registration. The general functional diagram of implementing the method is shown in Fig. 3. A photodiode ruler 1 is mounted on diaphragm 2 of photo recorder 3. The ruler is composite and consists of four separate rulers located in relation to the diaphragm 2 as follows: 1^{I} and 1^{III} immediately above it, and 1^{II} and 1^{IV} below it. Such an array cancels their inactive side parts and produces a practically continuous photodiode ruler along the entire length of the diaphragm. The light beams from the collimators 5, reflected by sensors 9, are focused on the diaphragm 2 in the form of a line. The middle parts of these

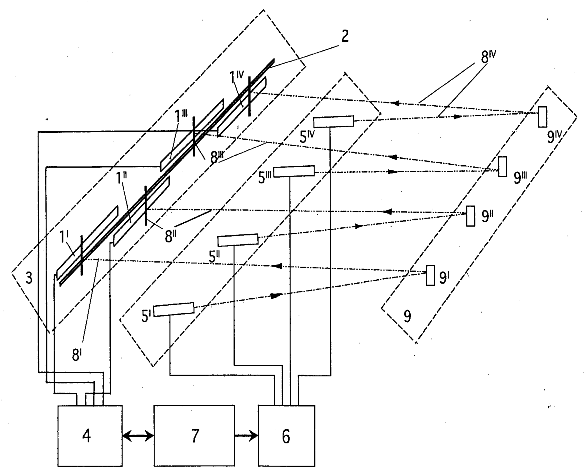

Figure 3.

beams perform the analog photo recording. The unused parts (for 8^{I} and 8^{III} – the upper ones, and for 8^{II} and 8^{IV} – the lower ones) are incident on the respective photodiode rulers 1. The outputs of 1 are connected to a unit for preliminary processing of the signals 4, which has a two-directional connection with the microprocessor system (computer).

Having in mind the geometric, optical and other design-performance characteristics of the analog magnetic photo recorder, it is most expedient to use an integrated photo sensor model TSL-218 of the TEXAS INSTRUMENTS Co. (Intelligent..., 1995). Four TSL-218 sensors, mounted on the diaphragm of the photo recorder (see Fig. 3), cover with some reserve the width of the diaphragm and the photo-paper tape, which is 200 mm. Consequently, this method of digital registration will allow to record deviation from the GMF parameters by approx. 25% higher amplitudes. The existing practice at the GMO has shown that during a geomagnetic storm the registograms of some GMF components come out of the diaphragm limits, i.e. there is no recording.

A basic problem is the identification of the recording traces of the separate components during a geomagnetic storm. This problem is solved here in the following manner. The collimators are not supplied continuously but according to a special cyclogram. In the initial version cyclograms shown in Fig. 4 and Table 5 were used.

As can be seen, in the registration of each GMF component there is an interruption of 50 s, which given the standard registration rate of the magnetic photo recorders *V* = 20 mm/h is expressed as an interruption of the analog registration trace by $\Delta t \approx 0{,}28$ mm. On the one hand, for such a short time the GMF practically does not change and, on the other, such an interruption on the analog registration is practically unnoticeable. Therefore, we cannot speak of loss of recording or information.

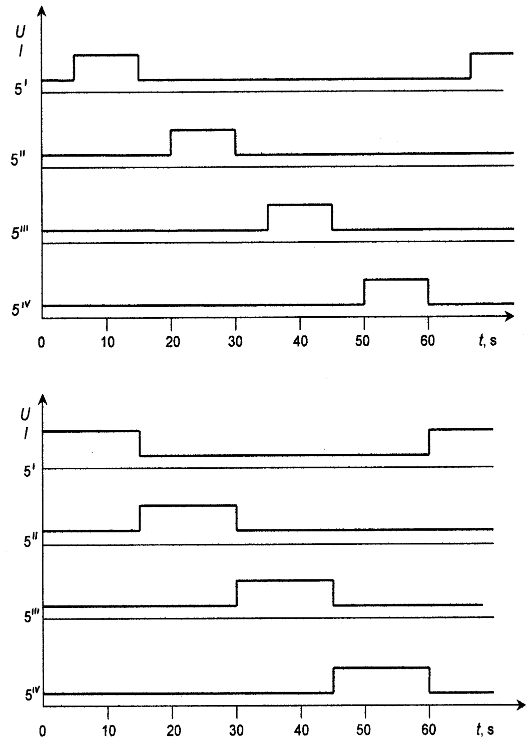

Figure 4.

At present the Panagyurishte GMO obtains data by the standard “mean hourly values”. With implementing the proposed method and equipment for registering the values of the GMF components several times per minute, a transition is made to the modern standard “mean minute values”. For this purpose, a cyclogram is introduced by which 5 values of each GMF component are recorded per minute. The collimators are switched on serially for 2 s with an interval of 1 s, i.e. within 1 minute there is a 10 s registration of each component.

Table 3.1.

Time from to s		Voltage supplied to collimator	Registered component of GMF
5	15	5^{I}	*D*
20	30	5^{II}	*H*
35	45	5^{III}	*Z*
50	60	5^{IV}	*F*

There are no technological problems to increase the number of measurements and registrations per minute, e.g. 1.5 s each without pauses, i.e. 10 measurements of each component per minute. The only limitation for an even higher frequency of measurement is the inertia of the illuminating lamps of the collimators. The experiments showed that it is approx. 1 s. In order to decrease this inertia and provide a more favourable operating mode of the lamps, their voltage is not completely cut off, i.e. the current does not become zero but is only reduced (see Fig. 4).

We believe that after a 2-year parallel analog photo registration and digital registration, and establishing its adequacy, the analog photo recording can stop. Besides, it is possible to decrease the optical arm (the distance between collimators – sensors and sensors – photo recorder by approx. 25 – 30% and even more. The number of photodiode rulers will be reduced accordingly since only one of about 50 – 70 mm length will be enough. In the absence of analog photo registration all light beams accomplishing the digital registration of the separate components *D*, *H*, *Z* and *F* are positioned and focused at the same point on that photodiode ruler, e.g. TSL-218 (Fig. 5). Thus the overall dimensions of the equipment are reduced, expensive photographic materials are saved, labour- and time-consuming manual operations are avoided, the equipment becomes cheaper due to the smaller number of photodiode rules, electric power is saved, the lifetime of the collimator lamps is extended, etc.

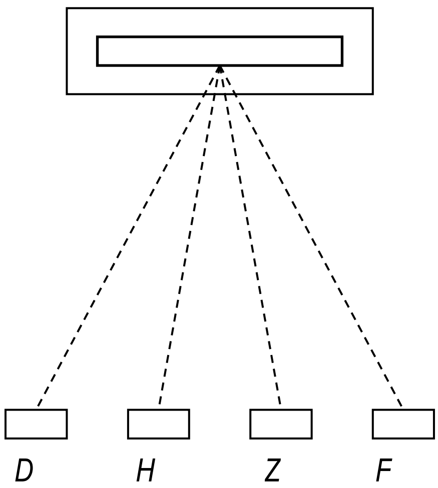

Figure 5.

Being produced by the same sensors, the proposed digital registration is suitable for processing, comparison and interpretation jointly with a long-term analog magnetic registration.

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