

# Magnetic measurements, apparatus and metrology

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**Abstract:** The magnetic field of the Earth is changing over time. Different kinds of changes – long-term (secular changes), daily changes and short-term changes – can be distinguished. The amplitude and character of these changes depend on the geomagnetic coordinates of the measurement point and current geomagnetic activity. Recently, instruments used for absolute geomagnetic measurements (magnetometer DI-fluxgate and proton magnetometer) have guaranteed high precision even at the level of 1 nT but the measurements of the geomagnetic field elements are not repeatable. Checking and testing the instruments for geomagnetic measurements must be performed only in a geomagnetic observatory which holds trusted apparatus that participated in the relevant international comparison campaigns organized by the International Association of Geomagnetism and Aeronomy (IAGA). After processing the results of the comparison campaign, the corrections for each instrument – for three elements of the geomagnetic field – are determined.

**Keywords:** magnetic field of the Earth, geomagnetic field changes, checking and testing the instruments for geomagnetic measurements

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## 1. Introduction

Instruments used for geomagnetic measurements, like all technical equipment should be reliable, i.e. ensure the required accuracy of measurements (Jankowski and Sucksdorf, 1996). Absolute or relative gravity measurements conducted in the same laboratory and at the same meteorological conditions in short time intervals should provide the same results, within the range of accuracy of the instrument provided by the manufacturer. For geomagnetic measurements it is not the case. The observed geomagnetic field is variable in time. Its changes depend on the geomagnetic coordinates of the point surveyed, the current geomagnetic activity and the local magnetic variations. Absolute measurements of the X, Y, Z components of the total intensity vector F of the geomagnetic field (Fig. 1) conducted at the same station and under similar conditions are thus not reproducible.

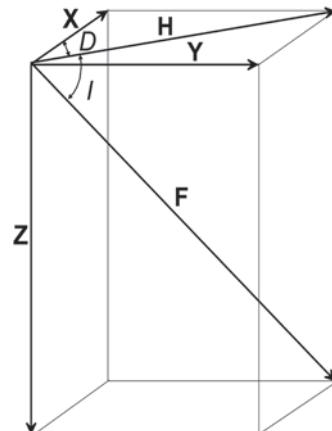


Fig. 1. Components of the Earth's magnetic field  
(D – magnetic declination, I – magnetic inclination)

The instantaneous values of the geomagnetic field components obtained as a result of the magnetic measurements may be related to the corresponding

set of instantaneous values recorded in the geomagnetic observatory. It is assumed that the conditions for magnetic measurement in the observatory are optimal. It is also assumed that the equipment used in the observatory meets appropriate standards which are systematically verified in comparison campaigns (Barton, 1991; Reda et al., 2011). Differences between the results of terrain measurements and measurements in the geomagnetic observatory, after averaging, can be used for further studies of geomagnetic field changes. The standard error estimated depends not only on the potential instability of measuring instruments, but also on local magnetic variations as well as on the difference between variations in the geomagnetic field in the area of measurement and the geomagnetic observatory. If the standard error of the differences between the results of field measurements and observatory records for  $D$ ,  $I$  and  $F$  geomagnetic field components is smaller than the accuracy of their determination in the geomagnetic observatory, it can be assumed that the instrument provides stable results. What is more difficult is checking the equipment used for geomagnetic measurements at sea, because the measurement error is additionally affected, besides by the ferromagnetic mass of the ship, by errors in maintaining the level of magnetometer sensors and their orientation with respect to the di-

rection of the true north. Maintaining the orientation of magnetometer sensors is essential to accurately determine the magnetic declination. The ferromagnetic effect of the ship and magnetic sensor orientation can be reduced using absolute magnetic measurements performed at the stations of the special marine magnetic network.

## 2. Checking the instruments in geomagnetic observatories

Magnetometer DI-fluxgate with – a non-magnetic theodolite with a magnetic sensor – and a proton magnetometer are currently used for the absolute measurement of the geomagnetic field components in geomagnetic observatories (Jankowski and Sucksdorf, 1996) and in field conditions (Barraclough, de Santis, 2011; Newitt et al., 1996). The theodolite with the magnetic sensor cap must be checked and certified as any surveying instrument. Absolute measurements of the magnetic declination and inclination require prior determination of the true north direction. After setting up the theodolite on the base pillar (Fig. 4) in the geomagnetic observatory the procedure of the determination of the instantaneous direction of magnetic north and thus the instantaneous value of the magnetic declination is carried out. The direction of the true north for



Fig. 2. Comparison of proton magnetometers

an absolute pillar is known. After magnetic measurements of declination (magnetic north) magnetic measurements of inclination should be conducted. The readings of the theodolite vertical circle (direction of the telescope toward the magnetic north) give instantaneous values of inclination directly.

The measurements with a proton magnetometer provide an instantaneous value of the module  $F$  of the total intensity vector of the geomagnetic field with the accuracy provided by the manufacturer (Fig. 2).

Checking the proton magnetometer – a similar device to a frequency meter – is a relatively simple procedure. Such magnetometer uses the relationship between the frequency of the precession signal of protons and the module  $F$  of the total intensity vector of the geomagnetic field. The most important is to check whether the internal generator of the magnetometer being a frequency standard is adjusted correctly. To ensure a common standard, the International Association of Geomagnetism and Aeronomy (IAGA) of the International Union of Geodesy and Geophysics (IUGG) recommends the use of the most recent value of the gyromagnetic constant for geomagnetic observations. The internal generator of the magnetometer is adjusted with respect to the reference frequency generator after placing the magnetometer probe inside the calibration coil, connected to the reference generator (Fig. 3).

In case of divergence exceeding the expected values the frequency of the internal generator magnetometer should be properly adjusted. Checking the non-magnetism of the probe proton magnetometer, by determining whether the results of measurements are independent of the orientation of the probe is also very important. As a rule, checking is performed in four set-ups: NS, SN, EW, WE. In addition, the record of the proton magnetometer should be compared with the record of another trustworthy magnetometer, for example the one used in the observatory. This is done by measuring the module  $F$  of the total intensity vector of the geomagnetic field in observatory conditions after placing the magnetometer probe on the appropriate pillar. Differences between the results of measurements obtained from the magnetometer being checked and from the base magnetometer in the observatory after averaging provide the correction which should be taken into account in the processing



Fig. 3. The coil developed in the Central Geophysical Observatory of the Institute of Geophysics of the Polish Academy of Sciences in Belsk used to check the proton magnetometer

of field measurements – of course, when it is greater than the measurement error. The analysis of the standard error allows the assessment of the operability of the magnetometer.

Slightly more difficult is to check the DI-fluxgate magnetometer used for measuring the declination and the inclination of the geomagnetic field. The community of magnetologists running worldwide geomagnetic observatories worked out a system of checking instruments for measuring Earth's magnetic field (Barton, 1991; Reda et al., 2011). IAGA coordinates the global network of geomagnetic observatories. IAGA Workshops on Geomagnetic Observatory Instruments organized regularly every two years in geomagnetic observatories in different places around the globe, are dedicated to the increase in the quality of geomagnetic observatory work, data acquisition and processing conducted in worldwide observatories and repeat stations. They offer metrological intercomparisons of the geomagnetic instrumentation of the participants, in particular intercomparisons of the DI-fluxgate magnetometers.

Results of comparisons together with the material based on the presentations at conference sessions of the workshop are published in the IAGA Workshop proceedings after each workshop (Reda, Neska, 2007). Comparisons are conducted on specially prepared pillars. Geomagnetic field variations are continuously recorded during the intercomparisons. This record is used for the determination of reduction correction, applied to eliminate from the measurement the effect of variations in geomagnetic field during the survey. This is very important because measurements of the declination and the inclination take 20-40 minutes, and the magnetic field is constantly varying, especially during the period of increased magnetic activity. During the IAGA workshops trainings is also offered in geomagnetic field observations and data processing. Such training is given by top world specialists. Notwithstanding IAGA Workshops, geomagnetic observatories mutually intercompare their DI-fluxgate magnetometers on the basis of bilateral cooperation.

Both intercomparisons of geomagnetic instrumentation during IAGA workshops (Fig. 4) and within the bilateral cooperation of the observatories ensure the uniform standard for geomagnetic field measurements at all geomagnetic observatories in the world. Instrumentation of geomagnetic observatories can therefore be considered as a reference

for national or regional magnetic repeat station networks.

### 3. Checking the instrumentation used for field magnetic measurements

Magnetometers used for the measurements of the magnetic field of the Earth in geomagnetic observatories can be considered as a reference with a high degree of confidence. This is due to the methods of checking the instrumentation used in geomagnetic observatories (described above). Therefore, the process of checking the instrumentation used for the measurements of the geomagnetic field components at the field magnetic points is based on the assumption that the observations of the variations in the magnetic field components in the observatory are correct. The instruments used for continuous recording of the variations in the magnetic field components  $X$ ,  $Y$ ,  $Z$  (different types of magnetometers) can be checked only by the synchronous recording by the tested magnetometer and the reference magnetometer with known parameters or the magnetometer in a geomagnetic observatory. If the records of the changes in the magnetic field components  $X$ ,  $Y$ ,  $Z$  from the two magnetometers are the same (within the accuracy of the instrument),



Fig. 4. The control magnetic measurements ( $D$ ,  $I$ ) – XII IAGA Workshop 2006 in Belsk



Fig. 5. The measurement of magnetic declination, inclination and module  $F$  of the total intensity vector on the base pillar in Belsk observatory

it can be assumed that the tested magnetometer works correctly. In the case of checking the DI-fluxgate magnetometer, after the control measurement session in the geomagnetic observatory (Fig. 5) the instantaneous differences between declination and inclination obtained from the tested magnetometer and the observatory magnetometer are calculated.

Averaged differences are considered as personal instrumental corrections to the observed magnetic declination and inclination at the field magnetic points. A proton magnetometer is controlled by the comparative measurements of the  $F$  component with the tested magnetometer and the reference magnetometer in the observatory. The magnetometer works correctly if the averaged differences between series are within the range of accuracy of the instrument. Sometimes such checking involves placing the probe in a special coil in which the magnetic field is generated with a known intensity (Fig. 3).

#### 4. Summary and conclusions

The nature of the Earth's magnetic field (continuous change in time) indicates the need for systematic checking of the instrumentation used for geomagnetic measurements, both absolute and relative.

Even in stable laboratory conditions, the geomagnetic field variations do not allow researchers to achieve repeatable results of geomagnetic measurements. Differences between the results from multiple geomagnetic measurements can be caused by both hardware errors and the local magnetic field variations.

In the analysis of the results of absolute measurements, the continuous registration of changes in the magnetic field components  $X$ ,  $Y$ ,  $Z$  changes by magnetometer located close the magnetic point may be helpful. This allows the elimination of local magnetic field variations during elaboration of the absolute value of magnetic declination and inclination.

The measurements of the total intensity vector  $\mathbf{F}$  depend only on the class of the proton magnetometer and its accuracy but the results must be checked in the observatory.

The magnetic equipment in the observatory is always the standard to which any investigation should be referred.

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# Metrologia a pomiary magnetyczne

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**Streszczenie:** Pole magnetyczne Ziemi jest polem zmiennym w czasie i zmiany te mają charakter długookresowy (zmiany wiekowe), dobowy (zmiany cykliczne) lub krótkookresowy. Charakter i amplitudy zmian zależą od położenia geomagnetycznego punktu pomiarowego oraz aktualnej aktywności geomagnetycznej. Aparatura wykorzystywana obecnie do tzw. pomiarów absolutnych pola geomagnetycznego (magnetometry protonowe lub magnetometry typu DI-fluxgate) zapewnia wysoką precyzję pomiarów, nawet na poziomie poniżej 1 nT, ale nie zapewnia powtarzalności wartości uzyskanych z tych pomiarów. Sprawdzanie, testowanie sprzętu pomiarowego może się odbywać w obserwatorium magnetycznym dysponującym zaufaną aparaturą, taką, która pozytywnie przeszła międzynarodowe porównania organizowane cyklicznie przez IAGA (International Association of Geomagnetism and Aeronomy). W wyniku odpowiedniej procedury pomiarowej i po opracowaniu wyników pomiarów otrzymuje się poprawki instrumentalne, które należy uwzględnić przy opracowywaniu wyników pomiarów terenowych.

**Słowa kluczowe:** pole magnetyczne Ziemi, charakter zmian pola magnetycznego Ziemi, sprawdzanie i atestacja sprzętu do pomiarów magnetycznych