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Векторный Оверхаузеровский магнитометр POS-4: опыт использования и перспективы применения

Vector Overhauser magnetometer POS-4: experience and prospects of application

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Problems with absolute magnetic observations

In recent decades, the development of magnetometers has made significant progress, especially with regard to devices *for measuring variations (dH,dD,dZ) and the total field intensity (F)*. However, with respect to magnetometers for measuring the full vector of magnetic induction (*absolute measurements*), progress is not so significant.

Almost everywhere, a set of two magnetometers is used for this kind of measurements:

1) scalar, usually based on an Overhauser or quantum sensor

2) DI-magnetometer (DIflux) using a fluxgate sensor mounted on a non-magnetic theodolite tube.

Such a set is the standard for the observatories of the INTERMAGNET network. However, with the relative stability of the results, DIflux requires manual work of a highly qualified magnetologist, has low productivity and some limitations due to the observation technology.

FGE-DTU fluxgate variometer

Variations

**1-10 Hz,
0.01-0.1 nT,
temperature dependence,
drifts**

dH
dD
dZ

D,I

**once a day - ones a week,
5-30",
manual**

F

**< 1 Hz,
0.01-0.1 nT**

Absolutes

Overhauser POS-1 magnetometer

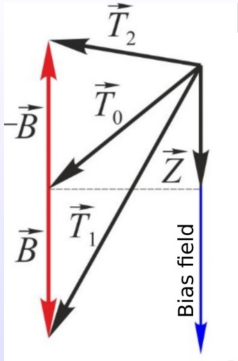
DI fluxgate magnetometer LEMI-203

Problems with absolute magnetic observations

One of the approaches for creating an automatic magnetometer for absolute observations is the automation of DIflux. AutoDIF and GyroDIF magnetometers have been developed and are already being used in observational practice, completely new devices with an automatic laser binding system to a remote reference point, a sensor rotation system and high-precision positioning (Jean Rasson). In addition, there are DIflux based on standard non-magnetic theodolites, in which manual manipulations and visual reading of the scale readings are performed automatically (Laszlo Hegymegi, Mingeo). Together with a scalar magnetometer, an automatic or semi-automatic system for measuring the full field vector is obtained.

AutoDIF during testing (Hyderabad observatory, 2014)

DIflux with electronic scale readings (Mingeo, Conrad observatory, 2018)



$$Z=\frac{T_1^2-T_2^2}{4B};B=\sqrt{\frac{T_1^2+T_2^2}{2}-T_0^2}$$

HZ-coils system with POS-1 sensor (Novosibirsk observatory, 2012)

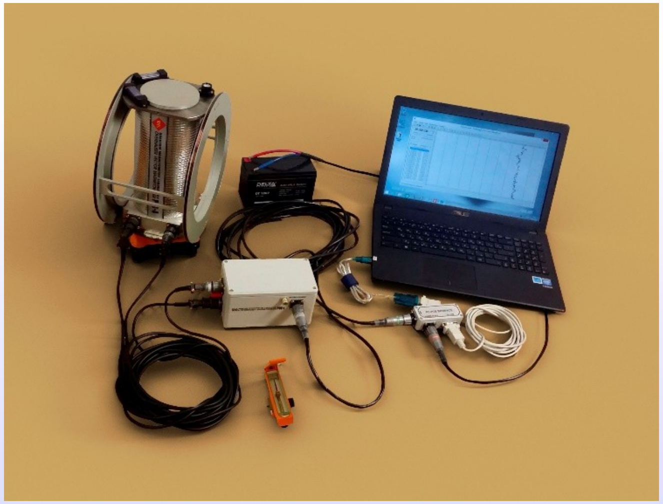
Another approach is based on the use of scalar sensors that measure the total field intensity F, placed in a system of coils that create compensating or additional fields in specified directions. Such systems were developed quite a long time ago and were used at observatories for absolute measurements of the horizontal and vertical components of the vector F, but they required careful tuning, calibration and a significant amount of manual procedures and time.

Vector Overhauser magnetometer POS-4 (description)

With the advent of sensors using the Overhauser effect and new technological approaches, it became possible to significantly automate measurements and calculations, minimize methodological errors and perform measurements with a frequency comparable to ordinary variometers. In practice, this approach was implemented on the basis of the developments of L. Hegimegy (Hungary) at GEM Systems (Canada) as the dIdD GSM-19FD magnetometer and in the Laboratory of Quantum Magnetometry of Ural Federal University (QMLab, Yekaterinburg, Russia) in POS-3 and POS-4 magnetometers.

dIdD GSM-19FD magnetometer (GEM Systems, Canada)

POS-4 Overhauser magnetometer (QMLab, Russia)

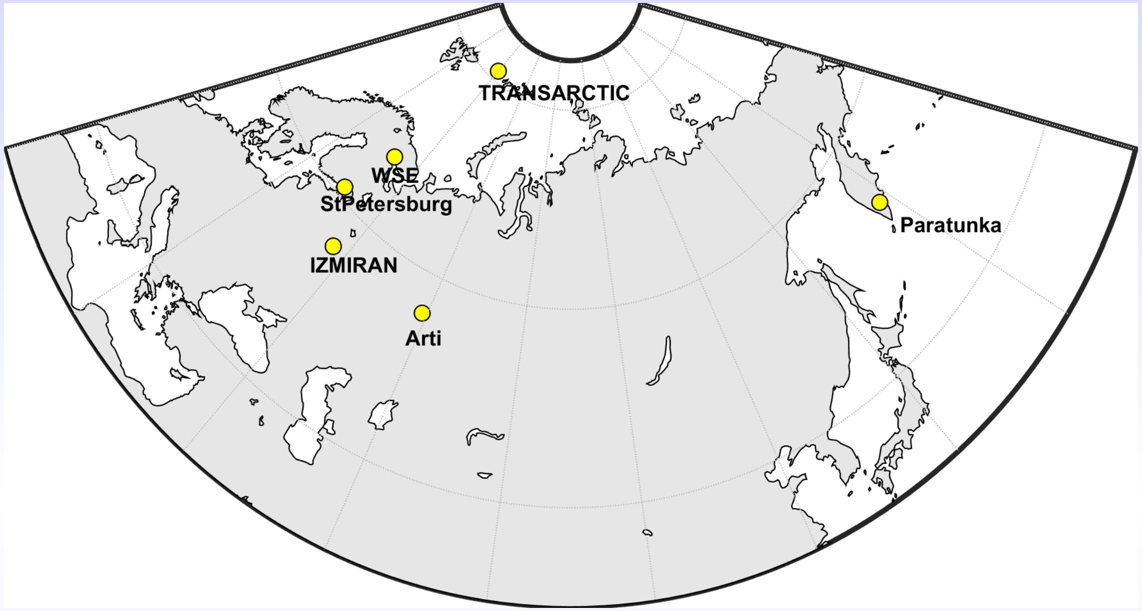


Assembly of the POS-4 magnetometer (from left to right: a solenoid with a coil system and a sensor, an electronics unit with a battery, an interface switching unit and a recording laptop)

The magnetometer consists of three key components: a magnetizing system, a primary probe (an Overhauser sensor) placed in it, and an electronics unit separate from the magnetic system. The electronics unit is connected to a computer that controls the magnetometer, processes and stores data.

The magnetic system creates a magnetizing field (uniform in the sensor area) in the direction of the measured field components. The vertical magnetizing field is formed by a vertical Garrett solenoid. The verticality of the solenoid installation is ensured with high accuracy by two mutually perpendicular liquid levels at the top of the solenoid. Additionally, POS-4 contains a magnetic coil system that forms a horizontal magnetizing field.

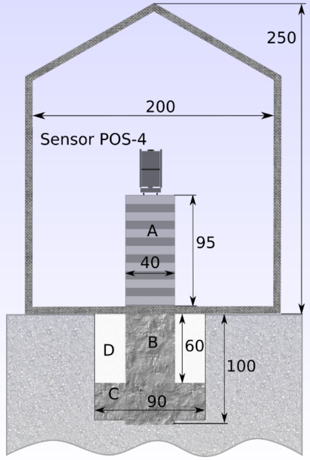
Vector Overhauser magnetometer POS-4 (locations)



Magnetic observatories and stations, where POS-4 magnetometers were used

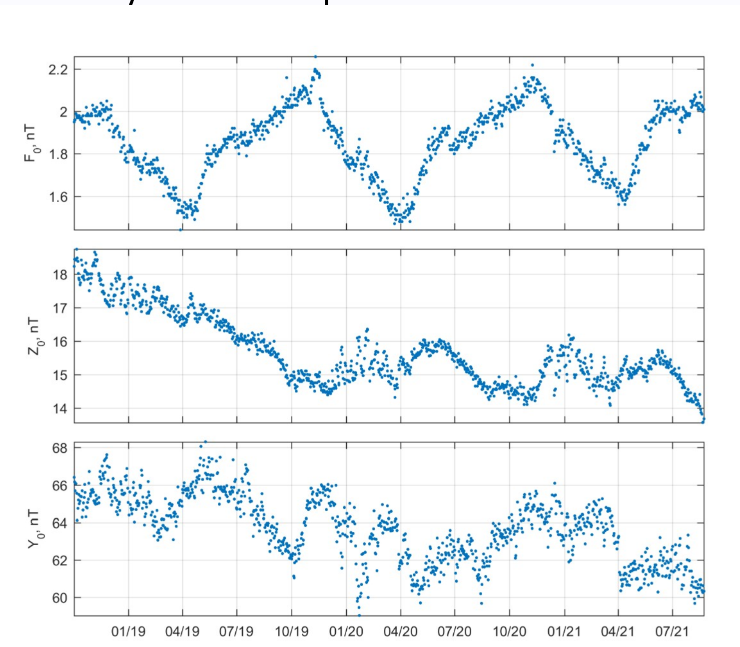
Arti (POS-3) 2011-
Paratunka 2015-
Arti (POS-4) 2017- irregular
AARI 2019- (TRANSARCTIC-2019)
SaintPetersburg 2018 (6 months)
WSE 2018-
IZMIRAN 2020-

POS-4 at observatory Paratunka, IKIR FEB RAS, Kamchatka



To install the magnetometer, a small 2x2 m wooden pavilion was built with an inner layer of expanded polystyrene for passive thermal stabilization. Such installation of the POS-4 provided full-fledged maintenance and carrying out various works, without interfering with other magnetometers of the observatory used for regular monitoring of the magnetic field. The noise influence during the generation of additional fields in the coil system and solenoid of POS-4 was also excluded. Inside the pavilion, a pillar was installed, in the lower part cast from a special low-magnetic mixture, and in the upper part made of glass blocks. There is no 220V power supply to the pavilion, there is no lighting and heating. To control the thermal conditions, three digital temperature sensors DS18B20 with a sensitivity of 0.1C are placed.

The POS-4 solenoid with a standard non-magnetic stand from theodolite is levelled using two high-precision bubble levels on its upper part. The horizontal axis of the magnetometer is oriented to the geographical East, so the values of the horizontal component are close to the current value of the component Y of the magnetic field. A recording laptop with a standard software POS Manager and a power supply system are installed in the technical pavilion at a distance of about 20 m. The measurement of single total field intensity value is 2 seconds, so the full cycle (measurement of the full magnetic field vector) takes 10 seconds.

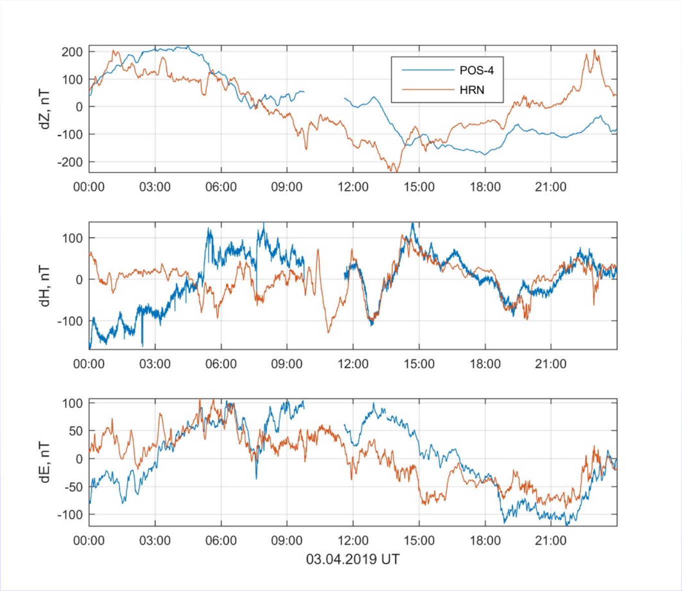


Daily mean differences between F,Z,Y measured by POS-4 and calculated from POS-1 (F) and DIflux (D,I) absolute observations (data since October 2018).

POS-4 during expedition TRANSARCTIC-2019, AARI

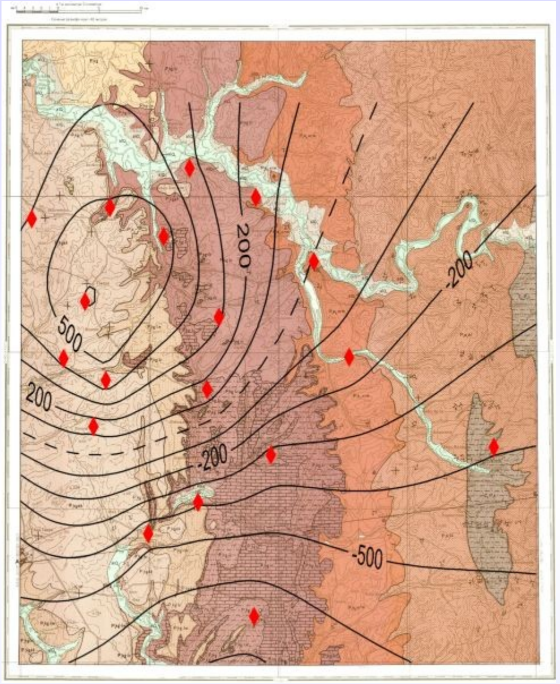
The expedition TRANSARCTIC-2019 started in March and lasted until May. A seasonal drifting research station "North Pole-2019" was organized on the basis of the vessel "Akademik Treshnikov"of the AARI of the Federal Hydrometeorological Service. The vessel was frozen into the ice north of the Franz Josef Land archipelago, from where it began its drift. The magnetic field measurements were included in scientific program of expedition.

The magnetometer was placed in a non-magnetic heated pavilion with non-freezing design for its emergency evacuation. The pavilion was made in St. Petersburg and then delivered by ship and helicopter to the installation site on the ice at a distance of about 400 m from the ship frozen in the ice. The magnetometer was installed in one of the corners of the pavilion on a tripod attached to the elements of the pavilion structure. The device is oriented vertically. The initial orientation of the device to the magnetic north is performed using a compass. The electronics unit and the laptop for data recording were located in the opposite corner of the pavilion.



The initial records of the variations dZ, dH(F,Z) and dE (the eastern component, the exact orientation of the Y axis is not determined) are shown in comparison with the second data obtained at the Hornsund Observatory (HRN, Svalbard Island, Norway, the distance to the expedition is about 800 km). As can be seen, there is a consistency of some features in the horizontal components of the field, a less expressive picture for variations of the vertical component.

The Geophysical Observatory Arti, IG UB RAS, Arti, Sverdlovsk region

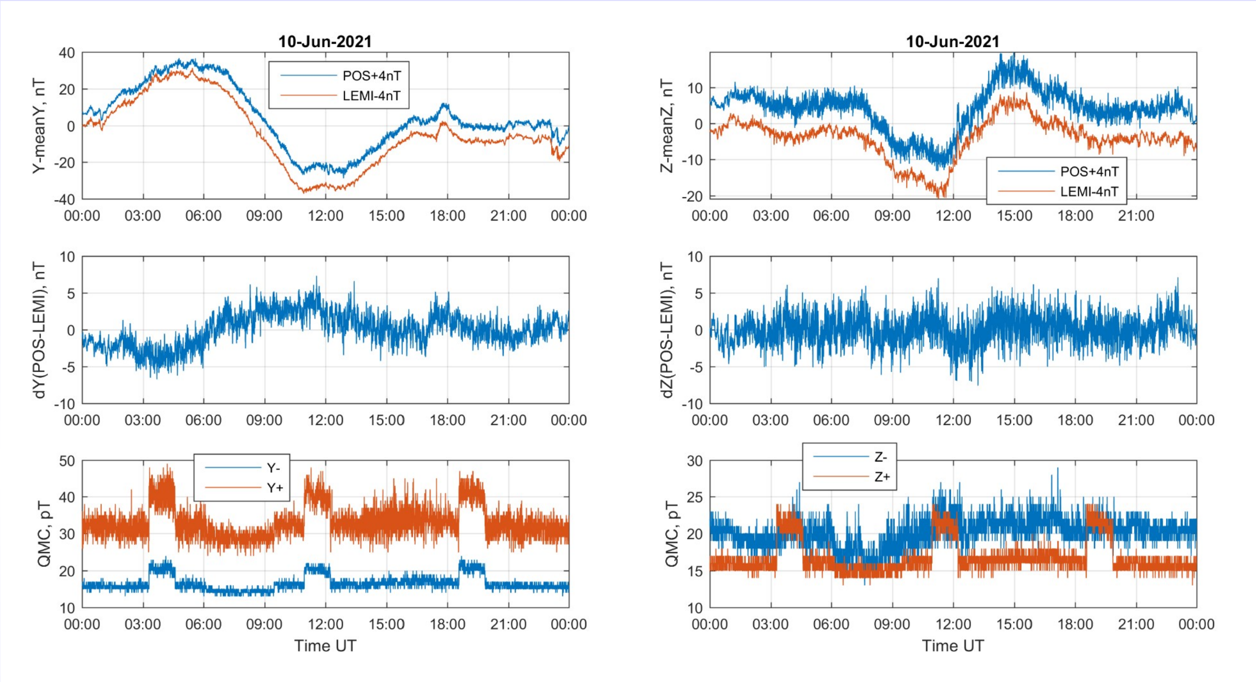


The Geophysical Observatory Arti of the Institute of Geophysics of the Ural Branch of the Russian Academy of Sciences is located on the outskirts of the urban village Arti, 180 km from Yekaterinburg. The close location of the observatory to the Laboratory of Quantum Magnetometry (Ekaterinburg), the presence of a developed infrastructure and various types of magnetometers operating in according to INTERMAGNET standards, and a low background noise level makes it an excellent place to test experimental QMLab developments, calibrate and compare magnetometers, check in real measurements.
Since November 2011 the POS-3 No.1 Overhauser ZT magnetometer, a prototype of the POS-4 serial magnetometer, are used at the Observatory Arti. POS-3 allows measuring the vertical and total field intensity. The main tasks for POS-3 were field measurements, including long-term measurements at the Repeat Stations when mapping the Manchazh gravimagnetic anomaly (Ural mountains) on an area of 50x50 km. Between field seasons, POS-3 is installed at the observatory for continuous measurements and various experimental observations.

ZT-magnetometer POS-3 No.1 during work on Repeat Station (left) and component magnetometer POS-3 No.5 with a digital tiltmeter on a test stand in a special verification pavilion (right)

Magnetometers POS-4 at the Observatory Moscow, IZMIRAN, Troitsk

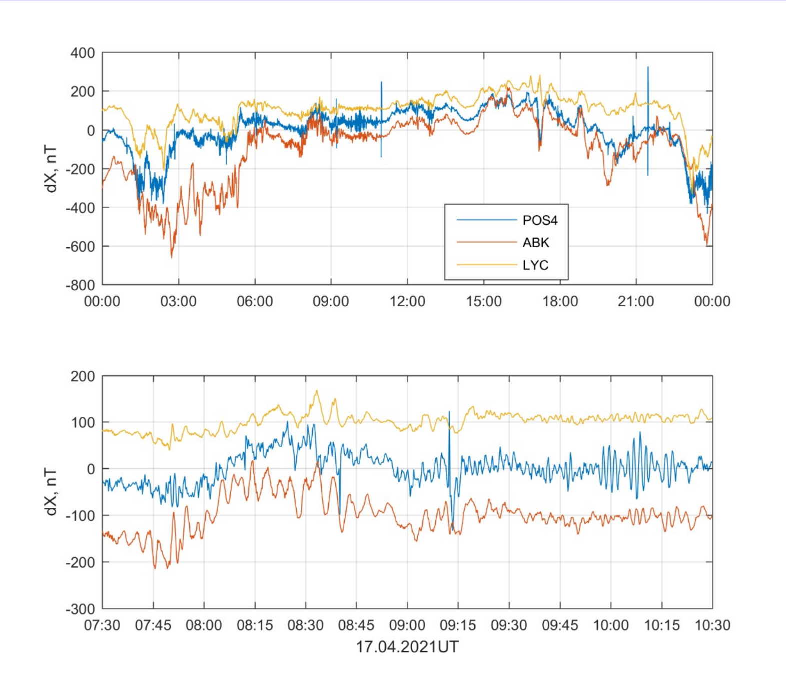
IZMIRAN acquired two POS-4 Overhause vector magnetometers at the end of 2020, including POS-4 (No.5) for the Observatory in Kaliningrad, and the second (No.6) for the magnetic station in the village Vaimusha, Pinezhsky district, Arkhangelsk region. Before being sent to the station Vaimusha the magnetometer No.6 was installed at the IZMIRAN Observatory Moscow in Troitsk in the absolute pavilion and tested for several months in a continuous measurement.



Sensor of POS-4 with tiltmeter at absolute pavilion, IZMIRAN

Figures shows the comparison of the raw second values of the variations of the Y- and Z-components obtained using POS-4 and the data of the LEMI-018 fluxgate magnetometer installed at the observatory Mikhnevo at distance of 80 km from IZMIRAN. The middle panels show the differences between the data of two magnetometers, the lower panel shows the parameter QMC (for measurements with two opposite magnetizing fields). As can be seen in figure the results of POS-4 are close to the results of the observational magnetometer, but they are more noisy during the day (primarily in the vertical component), with the exception of a small interval of 1-2 hours in the night local time. It can also be noted that the parameter QMC increases approximately every 8 hours, which indicates a regular source of noise near the measurement place.

Magnetometers POS-4 at the Observatory White Sea, GC RAS



The White Sea Magnetic Observatory (WSE) was organized by the Geophysical Center of RAS on the base of the White Sea Biological Station of Moscow State University: a non-magnetic pavilion with a glass block pillar was built on a specially selected site during June 2018, and a magnetometer POS-4 was installed and continuous measurements began in August 2018. POS-4 works almost completely independently, data is transmitted online to the GC RAS (Moscow) and is available on the website http://geomag.gcras.ru/dataprod-plot.html. The pavilion for POS-4 is not heated, i.e. the magnetometer is located in quite extreme conditions. Maintenance is performed sporadically, by employees of the GC RAS.

As an example, figure presents the 1-second data (the full measurement cycle is 15 seconds) obtained by POS-4 at the White Sea Observatory, compared with the data of the nearest auroral observatories Abisko (ABK) and Lycksele (LYC), Sweden. As can be seen, the variations of the X-component obtained using POS-4 are structurally close to the variations at the ABK and LYC observatories, it is hardly possible to expect a coincidence of details in the magnetic field variations at spatially separated points in the auroral area. However, in the highlighted three-hour fragment shown in the lower panel, it is possible to notice the synchronous manifestation of some features.

Pavilion of POS-4

Sensor of POS-4 at pillar

Discussion and conclusion

The advantages of the POS-4 magnetometer include:

1) structural reliability, compactness, absence of moving parts and elements made of brittle materials - this makes the magnetometer suitable for field work, in which the probability of mechanical damage to the equipment significantly increases;

2) easy to install, configure, run measurements and monitor results - this becomes very important when POS-4 are used in the absence of personnel with a sufficient level of qualification;

3) POS-4 allows us to obtain the elements of the magnetic field F and Z (and H) in the absolute sense, but with the frequency of variational measurements. In fact, there is a device that performs two functions that are mandatory for INTERMAGNET observatories. A methodological question remains open with the absoluteness of the horizontal component measured using a coil system;

Discussion and conclusion

The main problems for POS-4, which were discovered during POS-4 operation, were:

1) *a significant dependence of the measurement results on the stability of the base* (the slopes of the solenoid and the turns of the coil system). The problem was manifested in long-term trends in observational conditions, for example, at the Paratunka observatory during seasonal freezing and thawing of the soil under the pillar, or in field conditions when measurements were performed from a tripod. As a solution, it was decided to use a high-precision tilt meter, the non-magnetic sensor of which could be fixed on the upper part of the magnetometer solenoid. A similar method of accounting for tilts is used, for example, in fluxgate magnetometers MAGDAS. Currently, a method for compensating errors due to tilts has been developed and it is being implemented in the POS-4 software. Unfortunately, the control of rotations of the POS-4 sensor around the vertical, i.e. effects in horizontal components, remains open;

2) *a methodological problem related to the choice of the orientation of the coil system fixed on the solenoid and the orientation of the scalar Overhauser sensor POS inside the solenoid*. The orientation of the axis of this coil system determines which component in the horizontal plane will be determined. The orientation of the primary sensor with significant magnetizing fields in the vertical plane can increase the POS-4 intrinsic noise. Currently, the priority is to measure the eastern component and the orientation of the axis of the sensor POS perpendicular to the magnetic meridian. A similar problem, for example, is absent in the dIdD GSM-19FD, since the orientation relative to the field vector of pairs of declination and inclination coils is performed by aligning the readings in the measured channels (D+, D-) and (I+, I-);

3) *there is a problem with the solenoid stand used*, since its size does not provide sufficient stability on the pillar and sufficient sensitivity of the support screws when levelling. In addition, there is no possibility of precise rotation of the solenoid around the vertical axis (when studying a circular diagram or the orientation of the horizontal axis of the coil system), as is done, for example, with dIdD. Unfortunately, a possible solution by increasing the base of the stand and complicating its mechanical components may be acceptable only for the conditions of observatories and is not suitable for the field version;

4) *the format used for writing data to files by the standard POS Manager program* contains all the information that is obtained during measurements, including the measurement of each of the five modules is marked with its own time stamp. However, a certain problem arises for users who do not have the opportunity to develop their own software that would provide convenient work with data and minimize some methodological errors. Currently, as the experience of working with POS-4 in IZMIRAN shows, some changes have been made to the POS-4 file format, but it is not yet possible to assess how successful they are.

Discussion and conclusion

The tasks of automation of absolute magnetic measurements, including the creation of hybrid systems that combine the functions of absolute and variation magnetometers, remain relevant. In our opinion, the important aspects of these developments are the control of the spatial orientation of the measuring axes, noise immunity and ease of operation.

The experience of using vector Overhauser magnetometers POS-4 and its ZT prototype POS-3 for several years shows that trends in modifications of these devices reflect the requests of magnetologists in the tasks of observing the Earth's magnetic field.

The balance of achievements and shortcomings of the magnetometer POS-4 shown in this work gives reason to hope that in the future we can expect the appearance of a device suitable for the effective solution of a complex of scientific and applied problems, including observations under the Arctic and in tectonically active regions conditions.

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Thank you for your attention!