

Overhauser vector magnetometer POS-4: Results of continuous measurements during 2015–2016 at geophysical observatory "Paratunka" of IKIR FEB RAS, Kamchatka, Russia

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Abstract. The results of measurements by Overhauser vector magnetometer POS-4 carried out for one year and a half are presented. The accuracy, stability and reliability are evaluated.

1 Introduction

Continuous observations of the Earth's magnetic field are carried out for characteristic times from seconds to tens of years at magnetic observatories (MO). To provide proper results in such a wide frequency range, two types of devices are used at MOs of INTERMAGNET network, they are: (1) variometers ensuring high frequency and sensitivity but measuring only variations and/or having low long-term stability, and (2) magnetometers measuring the magnetic field in the absolute sense (full vector) but slow and requiring manual operation in general. Joint application of magnetometers of these types allow us to obtain acceptable results corresponding to INTERMAGNET standards [1]. Modern materials, new digital technologies and processing systems raise a question on the development of an automatic device providing the functions of both variation and absolute magnetometers. A high-performance absolute magnetometer AutoDIF was developed at the Meteorological Institute (Belgium, [2]) for almost continuous measurements of declination and inclination. Scalar magnetometers, Overhauser POS-1 or GSM-19W, are absolute devices to measure the total intensity of field. However, the problem of absolute measurements of field vector has not been solved yet. One of the attempts is the development of vector magnetometer POS-4 (Quantum magnetometry laboratory, Ural Federal University, Ekaterinburg, <http://magnetometer.ur.ru>).

2 Instrumentation, conditions of measurements

Vector magnetometer POS-4 is a new development; partially, technical and methodical questions of POS-4 were solved in a two-component magnetometer POS-3 [3]. POS-4 enables us to measure the

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Figure 1. Vector magnetometer POS-4. Left panel: a UPS is to the left, sensor (solenoid and ring system on the carrier) is in the center, electronic unit is to the right. Right panel: POS-4 hut, magnetometer sensor is mounted on a pillar made of building glass stones, the removable hut door is on brass bolts (March 2016)

magnetic induction F and two orthogonal components, the vertical Z component along the Garret solenoid axis and the horizontal projection of vector F on the axis of Helmholtz double-ring system. Moreover, the measured F and Z allow us to estimate horizontal intensity H . The magnetometer includes a measurement unit POS-1, high-stable current source and magnetic systems generating homogeneous switchable magnetic field:

- based on Garret solenoid with titanic frame, the vertical axis of which is adjusted according to liquid levels with scale factor up to 10^6 to measure vertical component Z ;
- based on titanic ring system perpendicular to Garret solenoid axis to measure F vector horizontal projection on ring axis in a random azimuth.

A nonmagnetic base (carrier) with a horizontal scale is used to mount the magnetometer on a pillar. The communication with a PC is provided by RS232 protocol. Standard software POS Manager is used for operation and recording of results. Sensitivity of total intensity is about 0.03-0.05 nT, that of ZH -components is about 0.15-0.30 nT, the module absolute error is not more than 1 nT, that of the components is 3-10 nT, measurement cycle is from 1 to 5 s. To some extent, POS-4 is an analogue of magnetometer dIdD GSM-19FD of GEM Systems (Canada). However, it allows us to estimate in absolute sense not only total intensity F , but the vertical Z component as well. We can also estimate one of the horizontal components (X/Y) when the ring system is oriented accurately. The device picture is shown in Fig. 1 (left panel).

IKIR FEB RAS purchased the magnetometer POS-4 in December 2014 within the framework of RFBR Grant [4]. One of the tasks was to evaluate the possibility of change to the instrumentation by Russian producers. POS-4 is rather an experimental device that requires different works (adjusting, control, testing) coordinated with the developer. Moreover, additional magnetic fields generated by the solenoid and the ring system affect the magnetometers located nearby. That is why a special nonmagnetic hut was built for POS-4. It is made of wooden balks, has the size of about 2×2 m, and

insulated (10 cm expanded polystyrene) from the inside. The pillar is made of building glass stones on a nonmagnetic base embedded into the ground by 1 m and has the section of $40 \times 40 \text{ cm}^2$. A glass plate is glued on the upper part. To reduce the possible noises, there is no 220 V power supply in the hut and active temperature stabilization is not provided. However, the temperature inside is being constantly measured by digital temperature sensors at three height levels. The general view of the hut and arrangement of POS-4 sensor are shown in Fig. 1 (right panel). The recorded laptop and the UPS are located in a technical hut at the distance of about 20 m. A standard communication and power cables are laid on the ground surface. The system is grounded on a ground stake near the technical hut. The magnetometer is not GPS-synchronized, UTC reference is realized via the laptop system time during measurement startup. The inner precision generator of the system provided timer stability for a month and more.

In April-May 2015, the magnetometer was tested in different operation modes with different orientation of the ring system (with the axis to the magnetic North, crosswise, according to geographic directions). In June the sensor was finally oriented with the axis of the ring system to the geographic "East-West". The POS Manager software records the results of measurements of five modules (with different polarity of magnetic fields generated by the solenoid and the ring system and directly measured), the date, time, measurement quality parameter QMC, as well as the estimated values of components Z and X,Y (X is the horizontal projection of vector F on the ring system axis). Further, we used only five initial values of the modules. Field components were calculated during the processing without application of any cleaning, smoothing etc. The field elements obtained by POS-4 directly and independently are F, Z (projection on the solenoid axis), Y (projection of the ring system axis). We assume all the components to be measured at the same moment (total cycle of 5 s). Other components were calculated by the obtained F,Z,Y.

3 Measurement results

Regular measurements of the magnetic field by POS-4 began in June 2015. Just like for other observatory magnetometers, certain requirements have been carried out for POS-4: logbook of the operations with the device, processing logs, device photography. Processing of the results is similar to the usual processing for other magnetometers and includes the following: estimation of baseline values (comparison with the results of absolute observations by standard DI-magnetometer LEMI-203 and a scalar magnetometer POS-1), calculation of minute values and output into standard format files, daily comparison with data of the main variometer at the observatory.

Fig. 2 (left panel) shows daily baseline values of POS-4 (differences between the POS-4 data and the results of absolute measurements after smoothing by approximating spine). Jumps in POS-4 record during adjusting of the sensor were removed (but shown for Y_0 as an example). The average of F_0 is fully explained by spatial gradient of F between POS-4 and absolute hut. Significant constant Y_0 on the undisturbed level is result of inaccurate orientation of the ring system to the geographic East.

It is clear from Fig. 2 that when F gradient stability is high, baselines Z_0 , Y_0 show significant oscillations from December 2015, the change rate is 2-3 nT/day. It is likely to be caused by instability of the pillar for POS-4 due to soil freezing. Movement of the pillar is confirmed by the readings of levels at the of POS-4 sensor, the changes reached several divisions, that is up to 1'. Fig. 2 also shows average daily outdoor temperature, recorded by a weather station. We see that at the end of November, the temperature did not exceed 0°C that could cause soil freezing around the pillar taking into account a low level of snow cover during the winter 2015-2016. The situation is even more complicated because the hut is not heated and air temperature changes significantly differ from the outside temperature, and the snow thickness around the hut is uneven. Significant influence during the freezing may be caused by insufficient ruggedness of the base when the weight of the pillar upper part

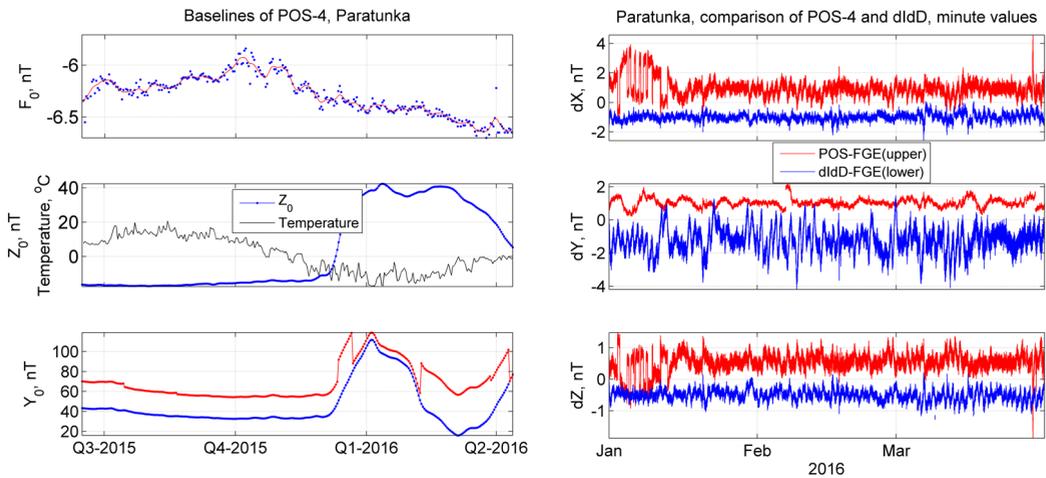


Figure 2. Left panel: adopted (smoothing spline approximation) baseline values of POS-4. Dots show daily mean of F_0 , the values of Y_0 are also shown before removal of the jumps during sensor leveling. The average daily outdoor temperature is presented at Z_0 panel. Right panel: comparison of minute data of POS-4 (top curves) and dIdD (low curves). Geomagnetic variations are subtracted (using of FGE magnetometer data). Curves are vertically shifted for better presentation.

made of glass stones is heavy. However, movement of the sensor itself (solenoid or the ring system) may also take place in the result of imperfect supporting base of the carrier or instability of additional field generated by the solenoid or the ring system. We may also note the clear drift acceleration Y_0) after a strong earthquake on January 30, 2016 which occurred at the epicentral distance of about 100 km from the observatory.

The variometer the POS-4 has an analogue, magnetometer dIdD GSM-19FD. Such magnetometers run in continuous mode at IKIR observatories. Fig. 2 (right panel) show minute value sets of both magnetometers for January-March 2016. Due to the strong trend in baseline values of POS-4, their interpolation was made for each minute. Geomagnetic variations were subtracted using the data of fluxgate magnetometer FGE, the main one at the observatory. We may note the following: (1) random components in dIdD and POS-4 data are comparable, it is somewhat higher for X- and Z-components of POS-4 and notably less for Y that is associated with the orientation of the primary sensor of POS-1 in the solenoid; (2) in Y(dIdD) significant variation is observed, it is correlated with temperature (the reason was not defined); (3) jumps in X,Z(POS) in January are caused by air temperature in the hut, however, the mechanism of the effect is not clear; small jumps are caused by adjustment of solenoid verticality.

4 Conclusions

Regular continuous measurements of the magnetic field by the vector magnetometer POS-4 at "Paratunka" observatory in 2015-2016 showed:

1) strong drifts of 2-3 nT/day and more are observed in the data of POS-4. They are likely to be associated with the instability of the pillar in the result of soil freezing and defrosting. Absence of an

automatically compensating system, similar to gimbal suspension of dIdD or FGE, requires a digital system of control for solenoid movement and temperature variations;

2) there is increased noise in Z-measurements of POS-4 (and its derivatives H,X) associated with the orientation of the primary sensor POS-1 in the solenoid that probably requires some change in the construction;

3) more reliable and effective construction for sensor mounting on the pillar is needed, it will provide better stability and accuracy of adjustment along the vertical axis;

4) being more compact and more simple in installation, POS-4 is comparable with the analog dIdD GSM-19FD as a variation device;

5) within more than a year of operation, POS-4 did not have significant problems both in registering hardware and software. However, lack of GPS-synchronization was inconvenient when adjusting the device.

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