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# Applications of Modern High-Precision Overhauser Magnetometers

E. D. Narkhov<sup>1, a)</sup>, L. A. Muravyev<sup>2, b)</sup>, A. V. Sergeev<sup>1</sup>,  
A. L. Fedorov<sup>1</sup>, A. Yu. Denisov<sup>1</sup>, A. A. Shirokov<sup>1</sup> and V. A. Sapunov<sup>1</sup>

<sup>1</sup>*Ural Federal University, 19 Mira Street, Ekaterinburg 620002, Russia*

<sup>2</sup>*Institute of Geophysics Ural Branch of RAS, Ekaterinburg, Russia*

<sup>a)</sup>Corresponding author: narhoved.ftf@gmail.com

<sup>b)</sup>mlev@mail.ru

**Abstract.** Increased sensitivity and resolution of geophysical instruments significantly enhances the effectiveness of non-destructive investigation methods for standard geological problems and allows new experiments. We suggest to use modern highly sensitive scalar magnetometers for identification and study of geological and artificial low-contrast objects in a magnetic field. We present application results of a modern nuclear precession magnetometer POS based on the processor Overhauser sensor. The device is developed and produced by the Quantum Magnetometry Laboratory, Ural Federal University, Yekaterinburg, Russia. Experiments conducted in the laboratory and observatories allowed to determine the device absolute accuracy of 0.5 nT and sensitivity of 0.02 nT, and to confirm its operability in large magnetic field gradients. This sensitivity is sufficient for detection of magnetic field changes caused, for example, by tectonomagnetic, seismomagnetic, piezomagnetic effects and electrokinetic phenomena in the geological environment. We conducted field experiments comparing POS magnetometers metrological characteristics with similar instruments from Scintrex and Geometrics. The results confirm measurement high stability in long-term observations of the magnetic field change due to geodynamic processes. We tested POS instruments in various geophysical applications, including prospecting and exploration of minerals (placer and ore gold, hydrocarbons, kimberlites); identification of ferromagnetic objects in cover environments; archaeological sites mapping. Our latest experience adds to this list a magnetic survey for pipeline inspection purposes. In addition, we discuss application of a novel absolute 3-component magnetometer POS-4 based on a principle of bias field switching method. The device was tested at several INTERMAGNET geomagnetic observatories. Due to high absolute accuracy and stability, there is a good prospect of implementing these magnetometers at observation points of long-term geomagnetic field secular variation and in autonomous magnetic observatories.

## INTRODUCTION

Increased sensitivity and resolution of geophysical instruments significantly enhances the effectiveness of non-destructive investigation methods for standard geological problems and allows new experiments. In particular, the growth in world mineral resources is currently associated with the prospecting and exploration of deposits that were not previously discovered due to the weak differentiation of search characteristics in the observed fields. We suggest to use modern highly sensitive scalar magnetometers for identification and study of geological and artificial low-contrast objects in a magnetic field. Examples are: spatial inhomogeneities in the upper part of the geological section; deep extended geological bodies; artificial magnetic objects; cultural layer.

## EQUIPMENT

We present application results of a modern nuclear precession magnetometer POS (Fig. 1) based on the processor Overhauser sensor. Using Overhauser effect leads to a more intense polarization of the sensor substance means to amplify the precession signal [1]. In addition, this is achieved by lower energy costs. This reduces the size

of the device and its power consumption. The device is developed and produced by the Quantum Magnetometry Laboratory of the Ural Federal University in the Yekaterinburg, Russia.

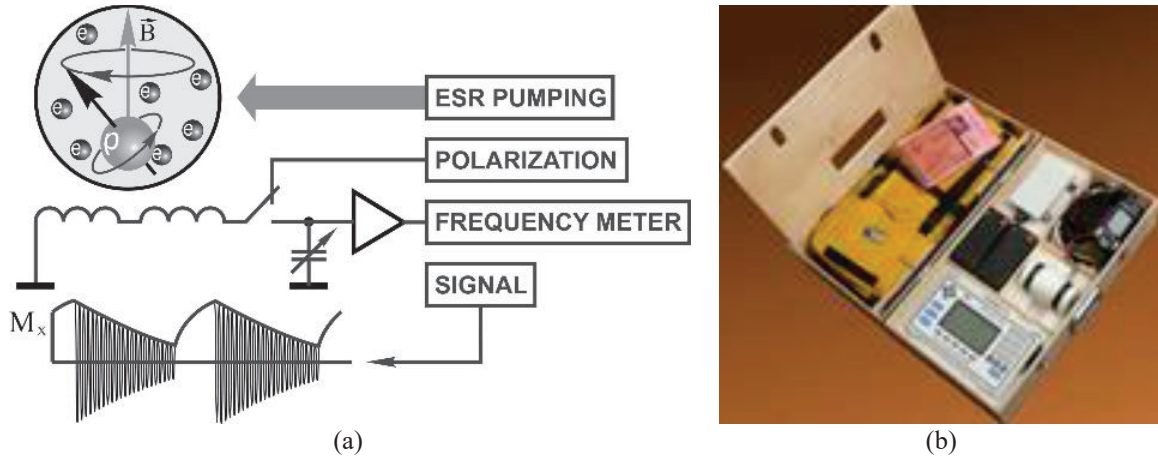


FIGURE 1. General scheme of dynamic nuclear polarization measurement (a) and device in the package box (b)

Experiments conducted in the laboratory and observatories allowed to determine the device absolute accuracy of 0.5 nT and sensitivity of 0.02 nT, and to confirm its operability in large magnetic field gradients [2]. We conducted field experiments comparing POS magnetometers metrological characteristics with similar instruments from Scintrex and Geometrics (Table 1).

TABLE 1. Characteristics of magnetometers POS, Geometrics G-858 and Scintrex SM-5

Characteristics	POS	Geometrics G-858	Scintrex SM-5
Sensor technology	Overhauser proton	Optical pumping of cesium vapor	Optical pumping of cesium vapor
Magnetic field measuring range	20000–100000 nT	18000–95000 nT	18000–95000 nT
Sensitivity	0.01 nT at meas. time 3 sec	0.008 nT at meas. time 1 sec	0.006 nT at meas. time 0.1 sec
Absolute accuracy	0.2–0.5 nT	(1.5 + 0.05 °C) nT	(2.5 sensor + 0.2 meas. circuit) nT
Sensor orientation requirements	Works in any orientation, with a non-optimal orientation error up to 1 nT	Works at 45° ± 35° to earth's magnetic field	10°–85° to the direction of the earth's field
Consumed current, power	300-400 mA, 4 W	600 mA, 10 W start, 7 W at 20°C	15 W start
Working temperature	–30 °C–50 °C	–15 °C–50 °C	–30 °C–50 °C
Thermostabilization	Not necessary	Continuous heating of sensors	Continuous sensor heating, temp. drift of 0.01 nT / °
Operating time from one set of batteries	1–2 days	3–6 hrs	2 hrs, when using add. batteries - 4 hrs.
Total weight of the kit	6 kg	6 kg	10 kg w/standard batteries + add. 5 kg battery
Measurements cycle	1 meas. in 3 sec, some models allow mode 1 meas. in 0.5 sec	seconds to 1 time in 0.1 sec	seconds to 1 time in 0.1 sec
Gradient resistance	20000 nT/m, 40000 forced mode	20000 nT/m	40000 nT/m
Sensor's lifetime	10 yr	≥3000 hrs	≥5000 hrs

The overall merit of all types of nuclear precession magnetometers relative to optical pumping (quantum) magnetometers is the absolute measurement of the magnetic field strength, which is caused by the physics of the process, which is not affected by the temperature factor. This makes it possible to use them not only in magnetic prospecting but also in observational practice for long-term monitoring observations. The main POS sensor distinguishing feature is the precession signal processor handling and the possibility of single measurement quality evaluating which done immediately after its implementation. The results confirm measurement high stability in long-term observations of the magnetic field change due to geodynamic processes. Our field experiments proved that revelation precision of geomagnetic field short term variations is reaching 0.05 nT, on the assumption of measurement moments synchronization. This sensitivity is sufficient for detection of magnetic field changes caused, for example, by tectonomagnetic, seismomagnetic, piezomagnetic effects and electrokinetic phenomena in the geological environment. In this case, the method of work involves placing one group of magnetosensitive devices near the studied object, and the other outside it and recording the difference in their readings.

## METHODOLOGY

All modern pedestrian magnetometers are equipped with receivers of the satellite positioning system (GPS). Each magnetic field measurement is accompanied by geodetic coordinates of the observation point. This increases the efficiency and performance of magnetic surveys. Satellite technology provides high accuracy and performance in measurement points coordinates determining, all-weather, the ability to work in the dark. Work quality operational control is provided. The operator can return to the coordinates for further investigation revealed magnetic anomalies. In real field conditions, we conducted qualitative and quantitative experiments to determine the accuracy of the determination of coordinates by GPS-type receivers. We have developed software for performing magnetic survey data primary processing: introducing magnetic field variation corrections, and GPS coordinates converting [3].

The use of satellite topography allows avoiding the preliminary observation network development, and if it is established, it is possible to realize the regime of continuous data collection on the survey route, not only at the points of the network, but also between them. Data is recorded at discrete intervals directly on the move.

We tested POS instruments in various geophysical applications, including prospecting and exploration of minerals (placer [4] and ore gold, hydrocarbons, kimberlites); identification of ferromagnetic objects in cover environments [5]; archaeological sites mapping, Figs. 2 and 3.

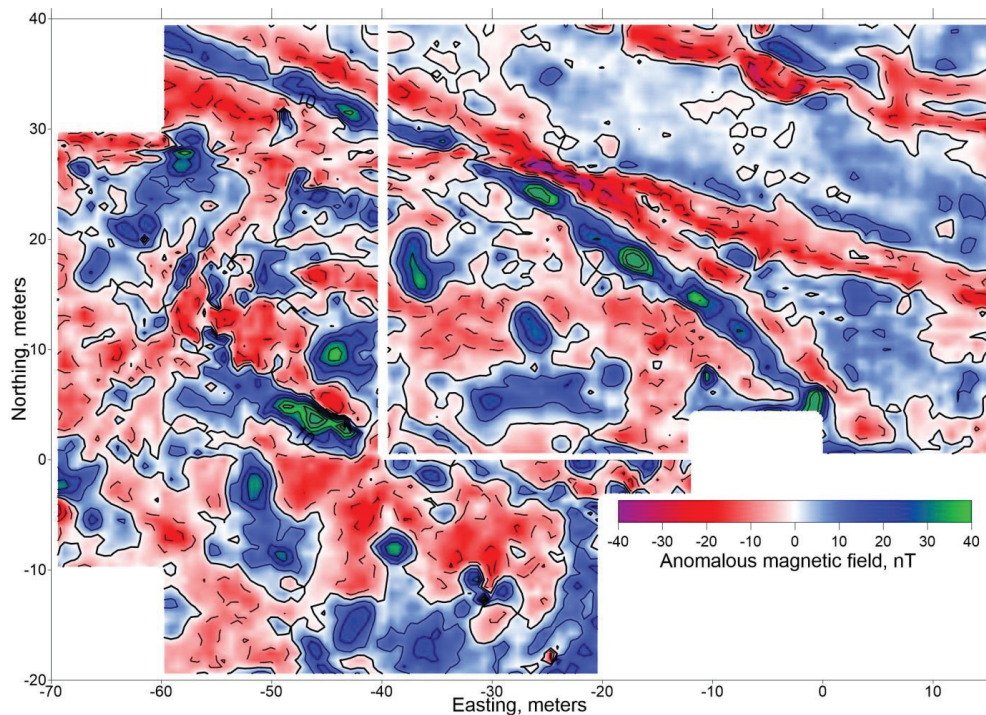
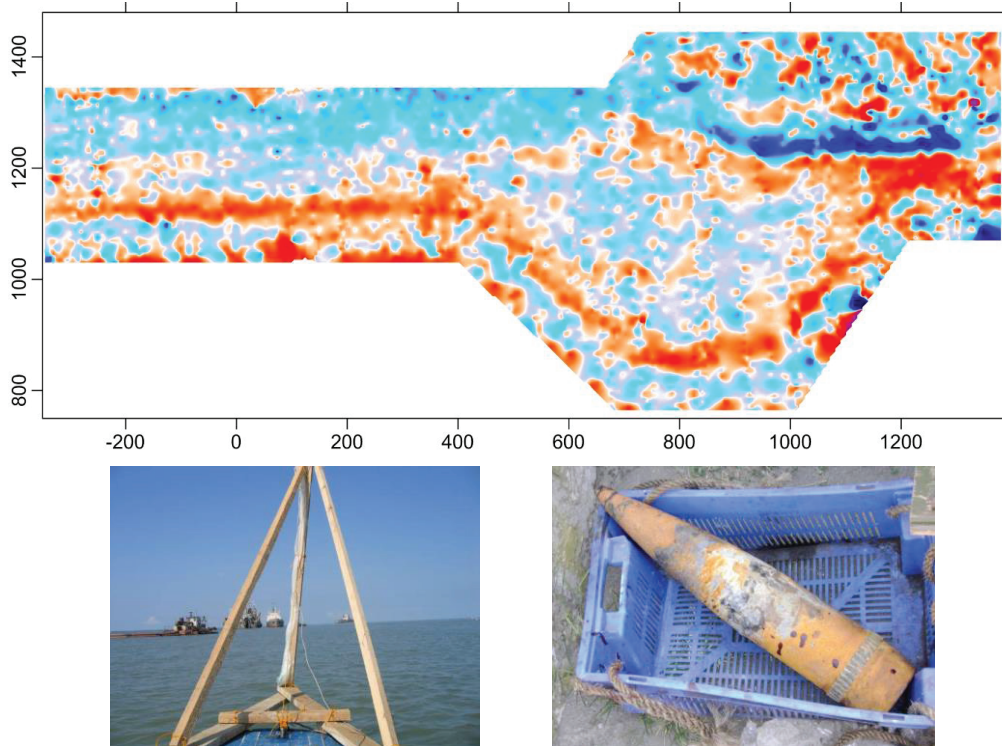
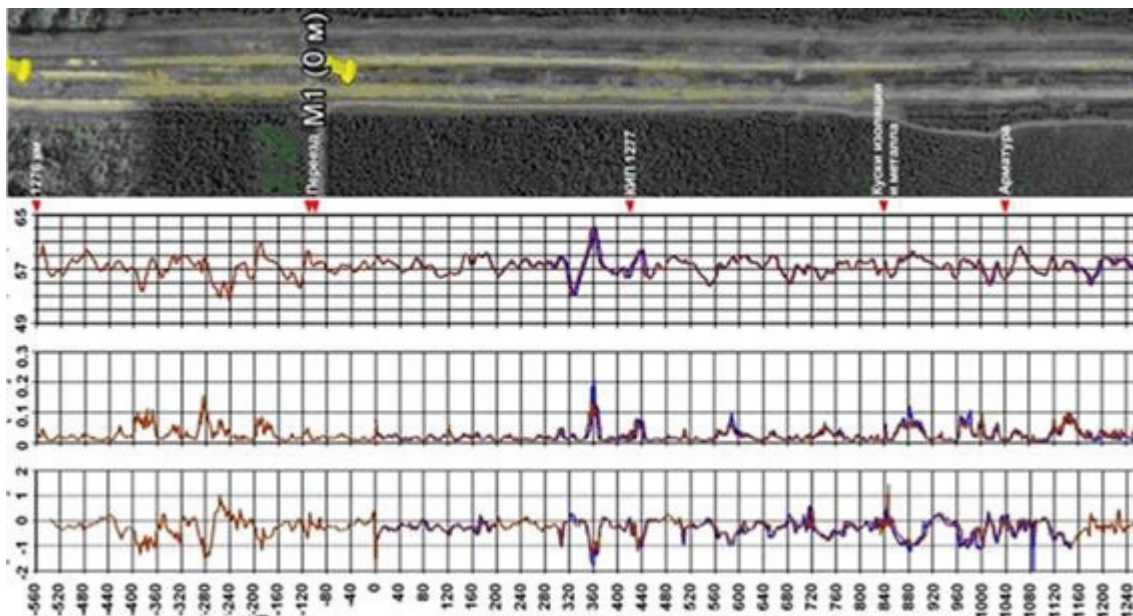


FIGURE 2. Magnetic survey of an archaeological site Olgino (Bronze Age, South Urals)



**FIGURE 3.** Magnetometric survey in the water area: map of local magnetic field anomalies (top). Installation of magnetometer sensors on a boat (left); shell from the sea bottom

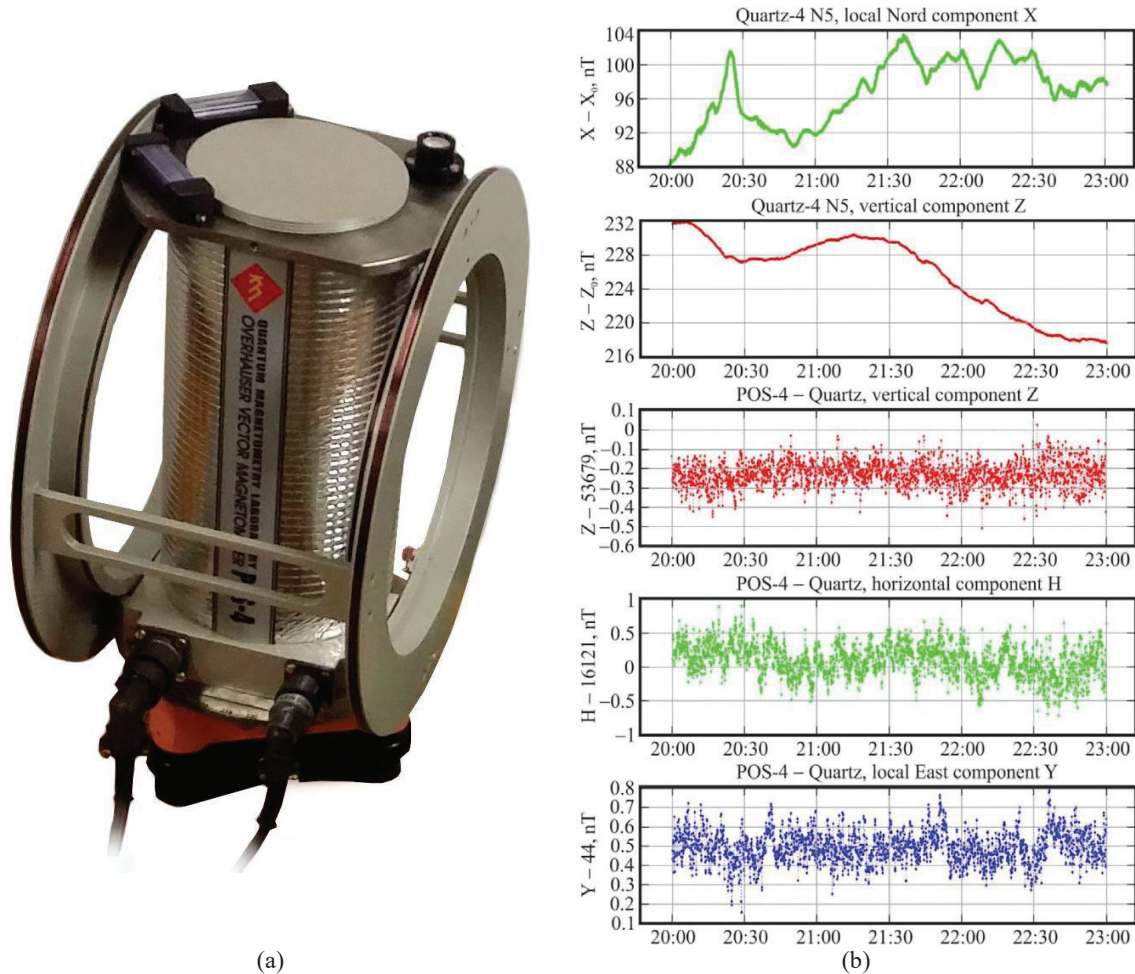
Our latest experience adds to this list a magnetic survey for pipeline inspection purposes. In aggressive environment, the modernization of existing pipelines and the building of new pipelines pose a number of problems to be solved for secure exploitation. Such problems include mapping, systems certification, technical inspection and monitoring (Fig. 4).



**FIGURE 4.** Magnetic survey for pipeline inspection: survey process (top); satellite view of the pipeline (middle); profiles of the magnetic field (TMI and gradients)

The usage of high-precision absolute quantum Overhauser POS magnetometers for surveying and the interpretation of the absolute value of the magnetic field of an object helps to make an investigation without interference into the functioning of the existing systems. The measurement of pipelines of different diameters, made of different types of pipes demonstrated the high reproducibility of measurements, thus leading to a new technical control type – a monitoring survey [6]. This type of technical control cannot only find the existing defects, but can also track the formation of new defects at the early stages.

In addition, we discuss application of a novel absolute 3-component magnetometer POS-4 (Fig. 5) based on a principle of bias field switching method [7]. The device was tested at several INTERMAGNET geomagnetic observatories. Due to high absolute accuracy and stability, there is a good prospect of implementing these magnetometers at observation points of long-term geomagnetic field secular variation and in autonomous magnetic observatories.



**FIGURE 5.** Vector/scalar Overhauser DNP magnetometer POS-4 (a); an example of Z and X components variations measured by Quartz-4 and Z, H, Y components of POS-4 relative to variometer Quartz-4 (difference to POS-4). RMS $\approx$ 0.1 nT. Date 2016:08:11, time is UTC. Observatory Arti (b)

## CONCLUSIONS

We tested these new magnetometers at the magnetic observatories Arti (Urals) and Paratunka (Kamchatka) for several years. Variant POS-3 measuring module and the only vertical component under the observatory Arti and

monitoring points of secular variation of the Earth's magnetic field around town Arti (Sverdlovsk region) are used. The first POS-4 full vector magnetometer (IdD+F) was tested at the observatory Paratunka for two years [8]. In addition to the state standard of magnetic field in metrology institute, St. Petersburg we used the equipment of the magnetic observatory Arti to test the metrological parameters in comparison with stationary installed vector magnetometers. We investigated the metrological parameters and calibration methods including self-calibration. Our studies shows the sensitivity of magnetometers for modul of field is about 0.02 nT, and for the field's components is  $0.1 \div 0.3$  nT with 1 second measurement cycle (the total cycle is 5 seconds). Fig. 5 display the examples of actual records in Arti. The new IdD+F POS-4 magnetometer is an analogue of the famous Canadian dIdD+F magnetometer applied both in observatories, autonomous stations and for directional drilling support of oil and gas wells [9]. The difference is in the absolute component measurement with the vertical orientation. The azimuth angle declination to the geographical north is provided by the telescope on the POS-4 magnetic system and GNSS markup that will be a DI+F absolute vector Overhauser magnetometer.

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