A Quasi Absolute Optically Pumped Magnetometer for the Permanent Recording of the Earth's Magnetic Field Vector

GeoForschungsZentrum Potsdam, D-14473 Potsdam, Telegrafenberg, Germany,
Contact E-mail: epulz@gfz-potsdam.de
***Keywords**: Geomagnetic observatories, vector measurements, second mean values, quasi absolute*

ABSTRACT

Despite the advance of technology, the fully automatic recording of absolute magnetic field variation at observatories remains an elusive goal. Primary difficulties are the long term stability of sensor orientation, and the stable operation of the sensor system. In standard practice, definitive data are produced through the combination of continuous operation of a variometer and the occasional absolute measurements that are used for calibration of the variometer data. A single, automatic instrument that can continuously acquire absolute vector measurements with 1-second resolution is desired. We introduce a device based on a Cs, Cs-He tandem magnetometer that will fulfil these requirements. Data are acquired using Serson's method: the ambient magnetic field is modulated by superposed fields. This method has been applied, mostly in connection with Proton magnetometers, for many years. In general it requires that the applied fields have a strength on the order of the Earth's magnetic field. But the sampling rate is limited for most existing systems. In contrast, our system only requires applied fields of about 5000nT and the switching rate of polarities is 5Hz. This is possible because we use a fast self oscillating Cs-magnetometer (optical pumped magnetometer, OPM). The self oscillating Cs-magnetometer is calibrated by a Cs-He cell during times without additional fields (sample & hold). We get continuously a frequency from an OPM which is strictly proportional to the ambient magnetic field. A laser will be used for precise orientation of coils.

INTRODUCTION

DIDD magnetometers are in use since several years. The aim of this method was to render manually performed absolute measurements unnecessary or reduce their number. The introduction of the Overhauser Effect Proton magnetometer for this purpose was a great success. Thereby the bias field could be reduced and the speed of the measurement sequence could be increased. A further improvement was obtained by the introduction of suspended coils [1]. However, still only the recordings of total intensity are absolute. The instability of the coil orientation remains a problem.

We develop a similar instrument using a He-Cs magnetometer [2,3] and an optically controlled orientation of the coil system. Here we benefit from the experiences which we have collected during the development of GAUSS [4].

THE MEASURING METHOD

In Serson's method [6,7], an additional field is added to the component to be measured. The coil axis is aligned with the component. Three measurements are necessary to determine the field strength in the direction of the coil axis: one without bias fields and two in both polarities.

The aim is to produce a complete set of magnetic field values every second. A set of two coils is necessary to obtain the full vector, with two measurements in each direction of coil axis and one measurement without bias fields. That means 5 measurements per second are needed. So, there are 200ms for each reading. Additionally one must take into account that it takes time to read out the frequency counter, and the time which the coil current takes to overcome the mutual induction. The frequency measurement time per reading therefore is 180ms. This time period is a multiple of 50Hz, so that we have always a full period of our European main power at each reading. This acts like a filter. The sequence of operation is shown in fig. 1.

The centre lines of both coils for generating the additional magnetic fields are perpendicular to each other and lie in the horizontal plane (in opposite to a DIDD). The system has to be levelled in the horizontal plane and one axis should be oriented to the true north direction (to measure the magnetic X-component). Both coils are connected in series. The advantages of this orientation and connection are the following:

- only half the current is necessary
- all 5 readings per second contribute a part to each component
- the noise level has nearly the same size in each direction
- the perpendicular error is eliminated

All measuring sequences are controlled in real-time by a PC. The coil currents are switched by electronic transfer switches. The whole arrangement is shown in fig. 2. We compute the generated bias fields from the measured frequencies. The knowledge of current and coil scale factors are not needed.

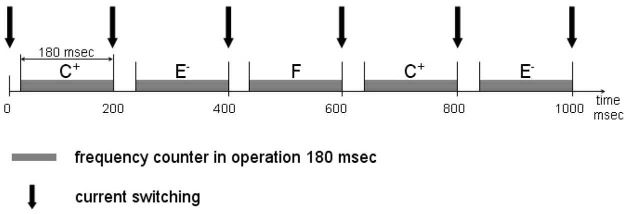

Fig. 1 Measuring sequence for each Second

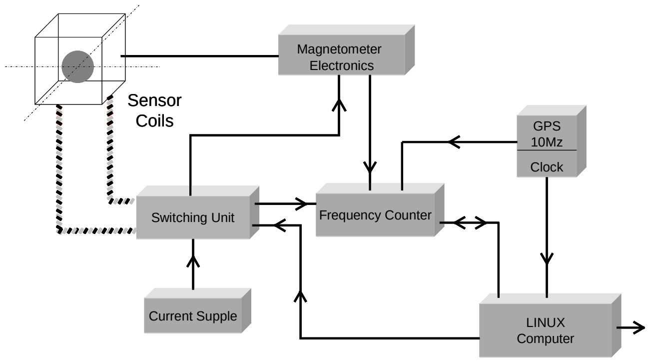

Fig.2 Measurement arrangement

THEORETICAL ESTIMATIONS AND LIMITS

The remaining task to get quasi-absolute measurements is a continuous control of the exact orientation. The theoretical estimation of the tilt errors of the coil system gave the following results: A deviation of +/- 1' from the horizontal plane leads to an error in the X component of +/- 13nT. A deviation from +/-1' of the azimuth angle gives an error in the X component of +/-1E-03nT. The coil system is suspended and is turn able. The levelling c is carried out magnetically by the turn able suspension of the coil system which is much more precise than a mechanical levelling. The suspension should hold the coil system permanently in position [1]. However, the direction shall be controlled by means of a LASER beam similarly to the one used for GAUSS [4]. The instrument will never be completely absolute but the time interval between manually performed absolute measurements can be increased significantly.
The required additional field strength depends only on the noise of the arrangement. The noise has different sources: First, the magnetometer noise and the noise of frequency reference; second, the noise of the bias fields; and third, the artificial noise at the observatory site. We found out that the total noise is less than 5 pT rms by 180ms reading time (see Fig.5). Based on this result we estimated that the additional field has to be in the order of 5000nT [6]. We are getting under these prerequisites the same noise of 5pT rms for the magnetic components.

CONCLUSION

We developed and built a very fast and low noise Cs-He-Cs tandem magnetometer. A software was written to control both the coils currents and the frequency counter in real-time, and to transfer the data to the host computer. One second values of the full magnetic field vector are recorded by this instrument.
Promising first results were obtained with a preliminary coil system. An improved coil system is under test. We will take advantage of our experiences with GAUSS regarding the orientation control in order to tackle this remaining problem.
When finished, we will have a high-accuracy magnetometer with excellent long-term stability, so that the number of manual absolute measurements can be reduced significantly. Consequently, one instrument at one place will provide the complete field information which up to now has to be obtained from three different instruments.

REFERENCES

[1] Hegymegy, L.
Observatory Instruments: Past, Present and Future'?
IAGA Conference (Division V), 2005, Toulouse, France
[2] Blinov, E. V., Ginzburg, B. L., Zhitnikov, R. A., Kuleshov, P. P.
Rubidium- Helium quantum magnetometer
Sov. Phys. Tech. Phys.* 29 *(12), December 1984 0038-5662/84/12 1362-05 $03.40
Copyright 1984, American Institute of Physics
[3] Kuleshov, P. P., Blinov, E. V., Shilov, A. E.,
Caesium-Helium Magnetometer with HFPH for High Accuracy Magnetic Measurements,
Proceedings of the VIth IAGA Workshop on Geomagnetic Observatories Instruments,
Data Acquisition and Processing, Dourbes (Belgium), September 1994
[4] Hemshorn, A., Pulz, E.
GAUSS: Improvements to the Geomagnetic AUtomated SyStem
Proceedings of the XIIIth IAGA Workshop on Geomagnetic Observatories Instruments,
Data Acquisition and Processing, Boulder/Golden, USA, 2008
[5] Pulz, E., Jäckel, K.-H., Linthe, H-J.,
A New Optically Pumped Tandem Magnetometer: Principles and experiences,
Meas. Sci. Technol. **10** (1999) 1025-1031
[6] Serson, P. H.,
Method of Making an Electromagnetic measurement,
Ottawa, Ontario, Canada, Canadian Patent No. 654, 552, Issued Dec., CLASS 324-1, 1962
[7] Jankowski, J. – Sucksdorff, C.,
IAGA Guide for Magnetic Measurements and Observatory Practice,
ISBN: 0-9650686-2-5, 1996