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A QUASI ABSOLUTE OPTICALLY PUMPED MAGNETOMETER FOR THE PERMANENT RECORDING OF THE EARTH MAGNETIC FIELD VECTOR

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At the Niemegk observatory, two different types of absolute measuring magnetometers were developed and built. One of them should replace the *D*/*I*-flux; it performs absolute component measurements at defined times (GAUSS). In this paper we describe an instrument which delivers every second a complete set of the Earth magnetic components in near absolute quality. It consist of a very fast Cs, Cs-He tandem magnetometer and a two dimensional coil-system and will be equipped with an optical system for the direction definition.

Keywords: recording of one-second mean values of the Earth's magnetic field components in near absolute quality

1 INTRODUCTION

A global map of the geomagnetic observatories shows they are distributed irregularly over the globe (Fig.1).
Observatories are mostly placed nearby densely populated regions, and there are many gaps around the world. A homogenous distribution over the Earth's surface would be desirable. That is impossible at the moment because only the scalar value of Earth magnetic field vector can be measured automatically. The main problem is the long term stability of sensor orientation. The measurements are currently subdivided into two parts: continuous relative variation recordings and distinct handmade absolute measurements for a calibration of these recordings. Absolute measurements of the total field intensity can be done by a scalar magnetometer, proton or optical pumped magnetometer.

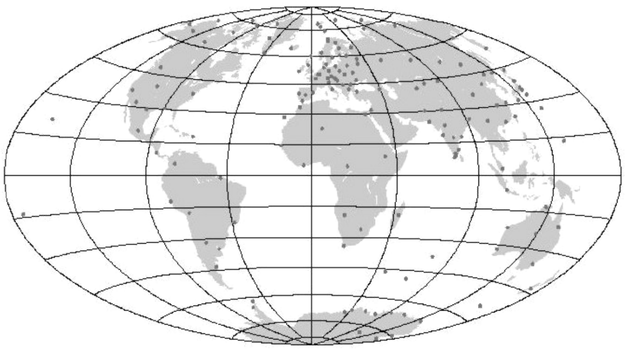

Fig. 1. Map of the geomagnetic observatories

The absolute measurements for the orientation of the field vector, however, are nowadays manually performed by means of a DI-flux consisting of an iron free theodolite and a one axial fluxgate magnetometer mounted on the telescope (Fig. 2).

The theodolite serves for determining of the coordinate system (horizontal plane, azimuth). The results of the full measurement are the declination angle, the inclination angle and the total intensity from a scalar magnetometer at a definite time. The measurement procedure includes the determination of all systematic errors, but the quality of the measurement results depends strongly on the experience and accuracy of the observer. Because of lacking manpower, regular absolute measurements are difficult to realize at remote areas. Fully automated observatories - that do not require manual operations of any instruments - are the prerequisite to fill the gaps in the global geomagnetic observatory network in remote areas.

At the Niemegk observatory, we develop two different types of instruments in parallel. One instrument should replace the DI-flux. It was reported about this instrument during the MM in Prague in 2004 [1]. There was shown our first prototype, an instrument that still had to be operated manually but following a more simple measurement routine. Based on that, we developed an automated instrument, see Fig. 3, [2].

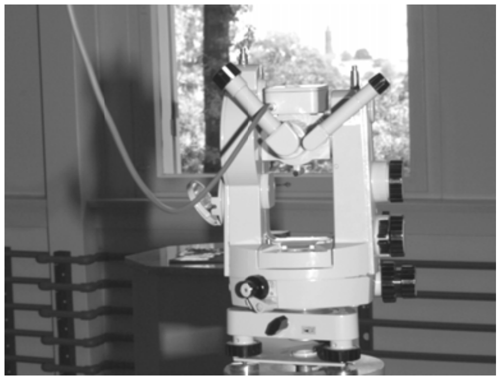

Fig. 2. Iron free theodolite with one dimensional fluxgate

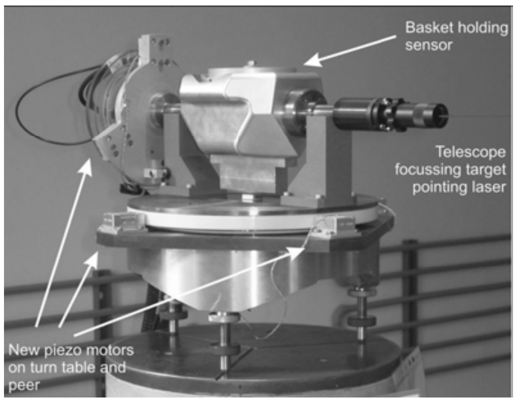

Fig. 3. GAUSS- the geomagnetic automated System

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Moreover, high time resolution (1 second mean) and field resolution data are requested from observatories in complementation to the modern satellite magnetic data.

The OPC may fulfill these requirements. It is delivering every Second a complete set of the Earth's magnetic components in nearly absolute quality.

DIdD magnetometers are in use since several years. The aim of this method was to replace the temperature sensitive three axial fluxgate magnetometers. An improvement was obtained by introducing the Overhauser Effect Proton magnetometers in connection with suspended coils [3].

However, still only the recordings of total intensity are absolute. The instability of the coil orientation remains a problem.

We developed a similar instrument using a He-Cs magnetometer [4, 5] and an optically controlled orientation of the coil system. Here we benefit from the experiences which we have collected during the development of [2]. The instrument is not yet completely finished but the results obtained so far are promising.

2 THE MAGNETOMETER

A Cs-He magnetometer [5] was selected for this purpose. The theoretical accuracy of this instrument is about 0.1 nT. We have compared our Cs-He magnetometer with our potassium magnetometers for more than 10 years and we found out that the actual accuracy is even better. The lifetime of a K-lamp is about 2 to 3 years. The Cs-lamp, which is needed to run a Cs-He magnetometer, has about 10 year lifetime.

Apart from the accuracy, two qualities are very important to reach the target aim: First the noise and second the resolution of the readings and time.

In a normal Cs-He magnetometer the response of magnetic field jumps is delayed. Therefore a new instrument was developed using the tandem principle (Fig. 4).

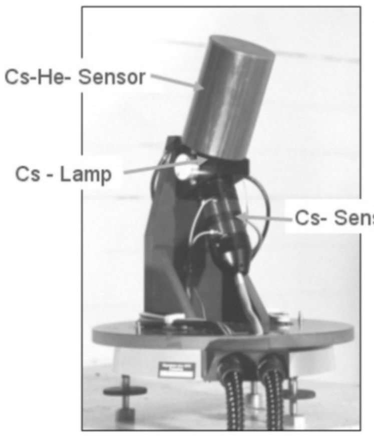

Fig. 4. Cs-He magnetometer

We made use of our experiences which we have gained from developing and manufacturing the Potassium-tandem magnetometers in the nineties [6]. The self oscillating Cs-magnetometer has a very fast response, and we had to take care that the noise level is very low.

The magnetic field signal T of the magnetometer is a frequency f with a strictly linear dependence and contains only atomic physical constants: $T = f/28.0236888$, (nT, Hz).

3 THE MEASURING METHOD

In Serson's method [7,8], 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

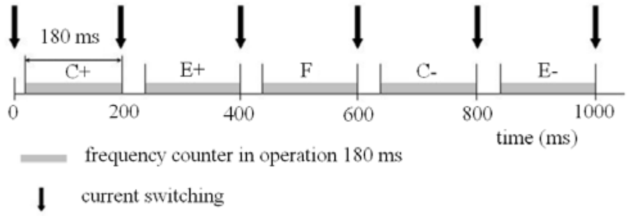

Fig. 5. Measuring sequence for each second

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 180 ms. 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. 5.

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

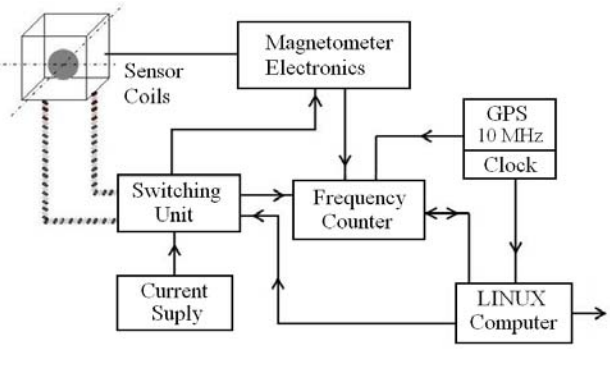

Fig. 6. Measurement arrangement

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. 6.

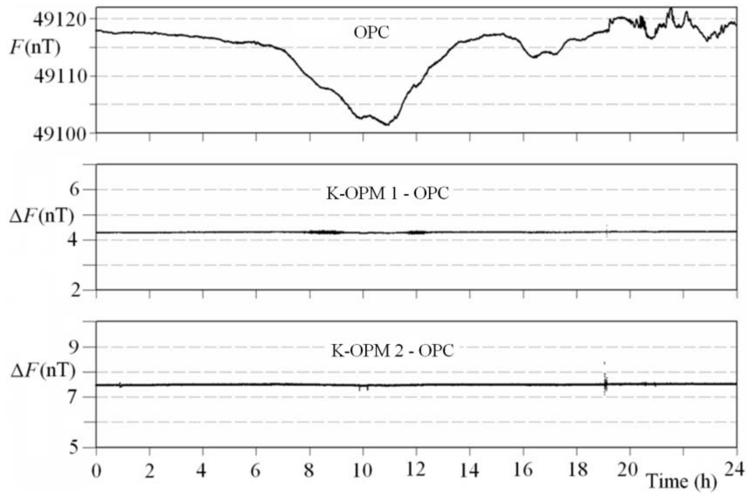

Fig. 7. Total intensity comparison at 2008-09-07

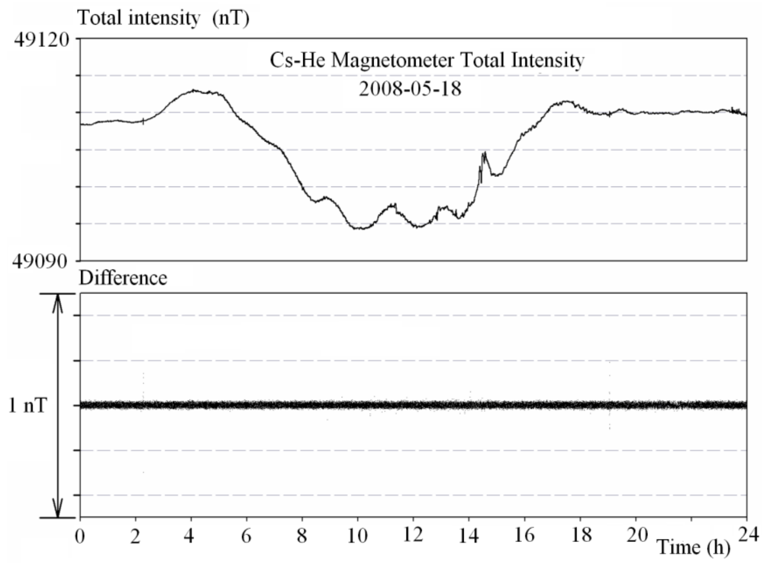

Fig. 8. Comparison of two successive readings without bias fields

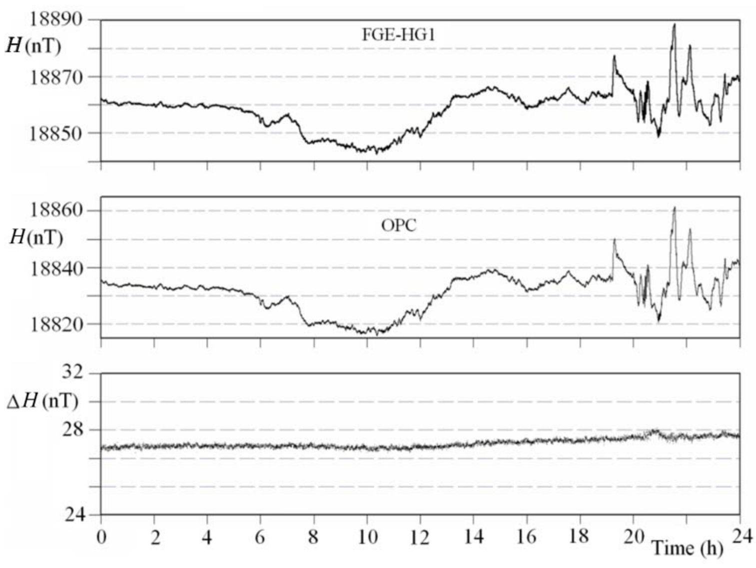

Fig. 9 *H*-component comparison at 2008-09-14

We compute the generated bias fields from the measured frequencies. The knowledge of current and coil scale factors are not needed. Up to now this instrument is a variometer.

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 ± 13 nT. A deviation from ±1' of the azimuth angle gives an error in the X component of $\pm 10^{-3}$ nT.

The coil system (not yet finished) will be suspended and will be turnable. The levelling can be carried out magnetically by the turnable suspension of the coil system which is very precise.

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.

3 THEORETICAL ESTIMATIONS AND LIMITS

The required additional field strength depends on the noise of the arrangement. The noise has different sources: First, the magnetometer noise; Second, the noise of the bias fields; and third, the artificial noise at the observatory site. The resolution is at the limit so that the noise of the reference frequency for the counter plays a important roll too. We found out that the total noise is less than 5 pT RMS by 180 ms reading time. Based on this result we estimated that the additional field has to be in the order of 5000 nT. We are getting under these prerequisites the same noise of 5 pT RMS for the magnetic components. Currently a provisional coil system is in use. It can only generate a magnetic field strength in the order of 3500 nT because the electronic transfer switches have a limited current. A new coil system, now under construction, will improve the results.

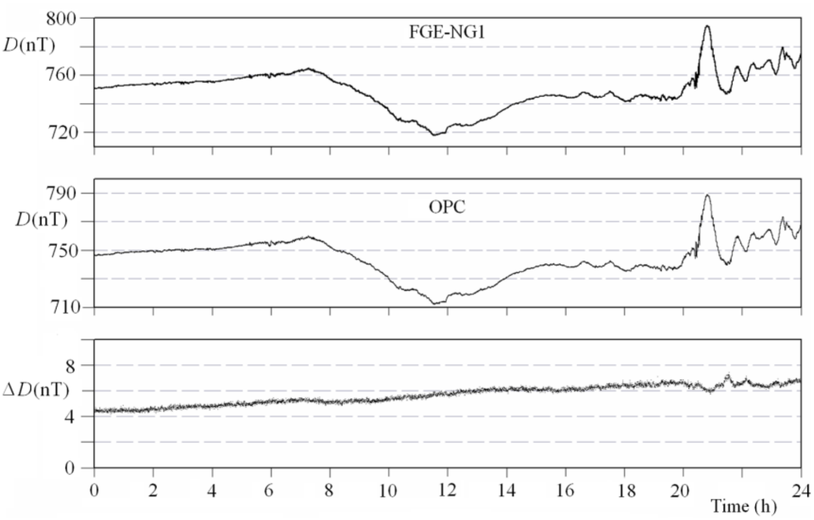

Fig. 10 *D*-component comparison at 2008-09-14

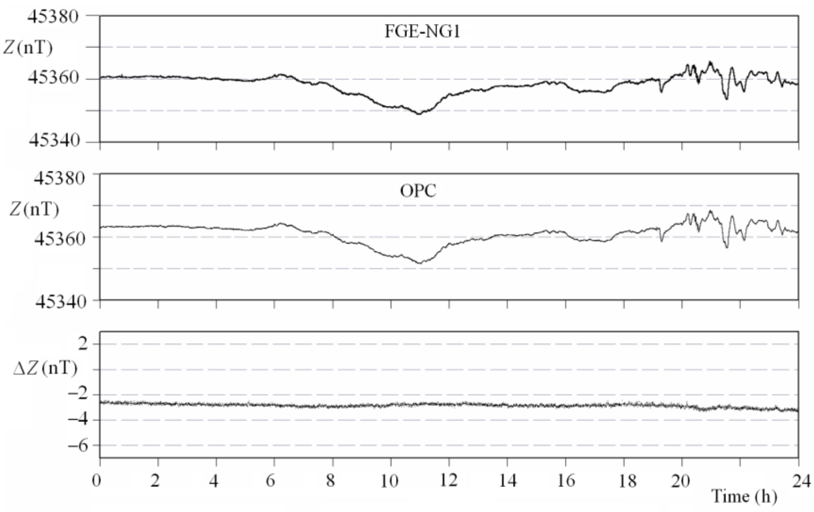

Fig. 11. *Z*-component comparison at 2008-09-14

4 RESULTS

Figures 7 to 11 show some actual results from the current setup of the instrument. Figure 7 shows a comparison of one second mean scalar values of the NGK K - tandem magnetometers to the Cs-He magnetometer (OPC) at which the reading time is only 180ms. It can be seen clearly that all magnetometers work excellently. A comparison between two successive readings while the bias magnetic field was switched off and was constant, respectively, was used for the estimation of noise (Fig. 8). The next figures 9, 10, 11 show the computed components *H*, *D* and *Z* in comparison to the observatory FGE variometer. A day with strong variation parts was selected deliberately (20:00 h). During times of high activity some small outliers can be seen in the comparison of the H-component. The reason could more be the distance (about 50m) between the magnetometers than the different kind of sampling. The sampling rate of the observatory FGE is two times per second and the OPC gives a one second mean value. As already mentioned, bias fields of only 3500 nT were used. Nevertheless it is obvious that the noise of components is similar to the FGE which is the standard observatory instrument. The component comparisons show slight drifts because the used provisional coil was not aligned precisely.

CONCLUSIONS

We developed and built a very fast and low noise Cs-He-Cs tandem magnetometer with electronic transfer switchgear.

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 which will reduce the noise is currently being manufactured in our workshop. We will take advantage of our experiences with GAUSS [2] regarding the orientation control in order to tackle this remaining problem. When finished, we will have a high-accuracy magneto-meter 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.

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