Project and Manufacturing of an Autolevelling Vectorial Magnetometer for Volcanic Areas Monitoring

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Abstract

In the frame of EPOT project (technological innovation and automation in the integrated applications of Electromagnetic and POTential field methods in active volcanic areas) an auto levelling magnetometer for geomagnetic field monitoring in volcanic areas, was proposed. In this paper a brief description of this magnetometer and some preliminary tests are described. In particular some characteristics of the non-diagonal elements of the field transform matrix **A** between the observatory system and the magnetometer placed in a far location are discussed with the relative implication when one of the two magnetometers would be located in a volcanic area.

Key words *autolevelling magnetometer – magnetic monitoring - thermal drift*

1. Introduction

Magnetic monitoring of volcanoes is made generally by means of proton precession magnetometers for total field measuring. However these observations, although very useful and effective [Stacey et al., 1965; Johnston and Stacey, 1969a; Johnston and Stacey, 1969b; Johnston and Muller, 1981; Johnston and Muller, 1987; Zlotnicki et al., 1993; Zlotnicki and Bof, 1996; Avdeev et al., 1997], provide only partial information because changes of local magnetic inclination and declination could cause null changes of the total field. Moreover the scalar measure of the local field does not furnish information on changes of the X, Y and Z components. On the other side the employment of vector magnetometers in the uninterrupted monitoring of the geomagnetic field, presents different problems in relation to the physical conditions of the volcanic areas: fluctuations of the apparent vertical, torsional movements, strong distortion of the geomagnetic field lines, intense local magnetic field gradients, are in fact only some of the most important remarkable characteristics of these areas [Rikitake and Yokoyama, 1955; Davis et al., 1979; Muller and Johnston, 1981; Meloni et al, 1998; Sasai et al, 2001; Sasai et al. 2002]. In particular, the fluctuations of the apparent vertical can cause effects on the X, Y and Z components; therefore the reference system materialised by the sensor axes, should be inertially coupled to an absolute reference frame. The distortion of the local field lines is reflected on the sensor orientation while the field gradients are reflected on the precision of the measurement since the field is integrated over the space occupied by the sensor.

In order to try to solve these problems we propose here the theory and realization of our autolevelling vector magnetometer that can properly operate in volcanic areas. The new designing criteria have been oriented towards a high long term stability and a low thermal drift. This instrument can be employed for continuous measurements of the geomagnetic field in remote stations, where regular carrying out of absolute measurements cannot be guaranteed.

2. The magnetometer

A prototype of the autolevelling magnetometer here proposed was realized at the geomagnetic observatory of L'Aquila, Italy. The magnetometer consists of a flux gate sensor, its driving electronic circuits (Fig. 1) and data acquisition system. The magnetometer allows fluctuation adjustments of the bearing surface with an indeterminateness of less than 4" and a dynamic extension of ±5°. The geomagnetic fluxgate sensor was designed in order to strictly fit the proposed technical requirements.

The sensor hanging system was made using a compound gimbals with amagnetic ball-bearing made with copper and beryllium alloy (Fig. 2). The non-orthogonality of the hanging planes (materialized by the suspension) is less than 0.1°.

Since the best geometric shape for a fluxgate sensor is the toroidal one, the sensor was constituted of two torus each with two copper windings. Each nucleus measures two geomagnetic field components: the first sensor measures horizontal elements X and Y while the second one measures Y and Z components. In this way two different measurements of Y component are obtained. This opportunity is used to minimize the noise using appropriate software.

In order to choose the best material for the sensor realization, measurements of background noise in crystalline and amorphous materials have been implemented in different

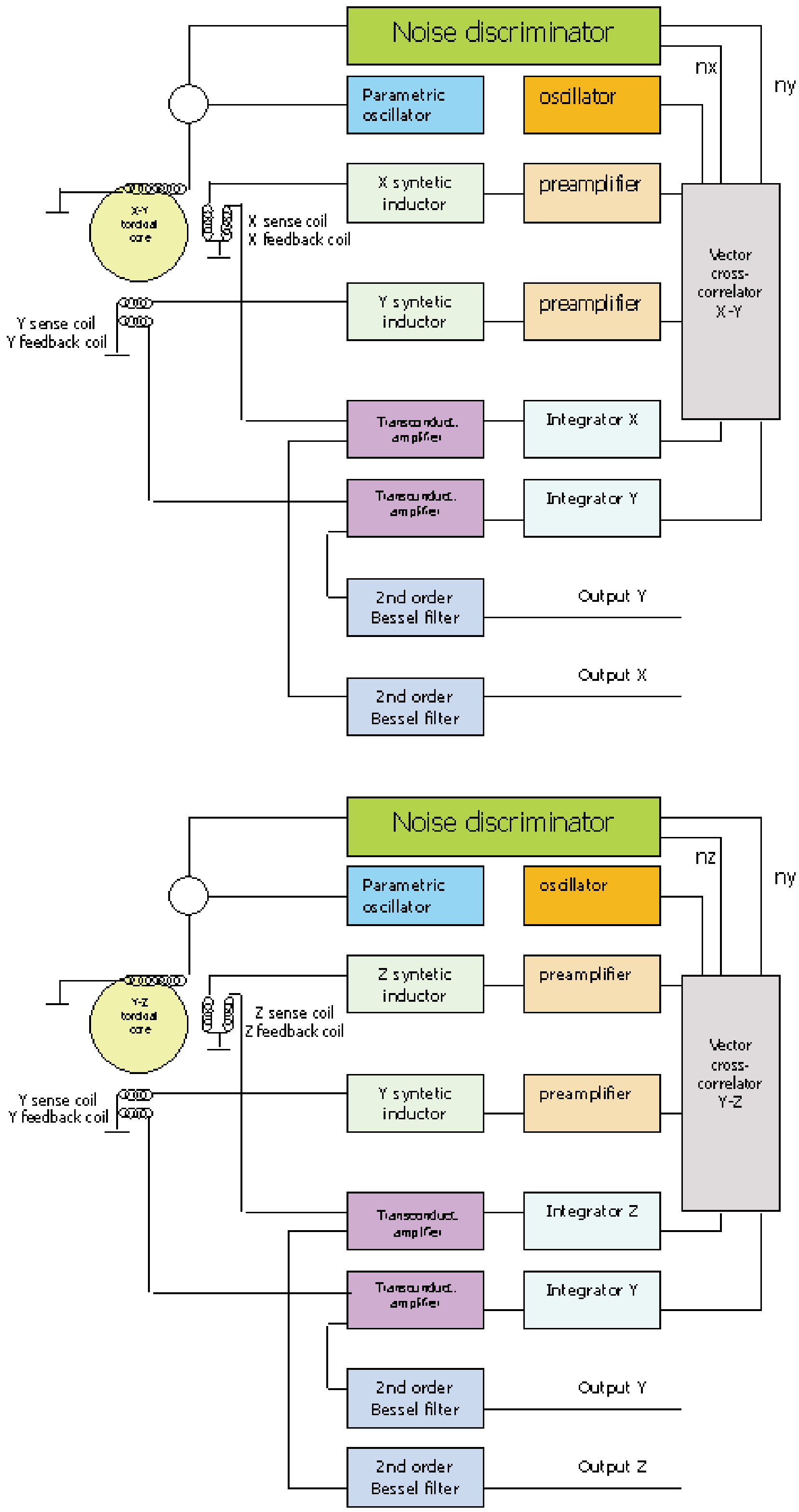

Figure 1. Synoptic scheme of the tri-axial two core magnetometer sensor.

environmental conditions. With respect to crystalline materials, amorphous materials were found to satisfy the following peculiar characteristics [Igoshin and Sholpo, 1979]:

1. 5-10 times lower magnetostriction coefficient
2. lower Barkhausen noise
3. lower general noise (1/f)

The analysis of the collected data in fact shows best results by materials with low level of internal structure of crystallization. In particular the VITROVAC 6025 showed the best perform-

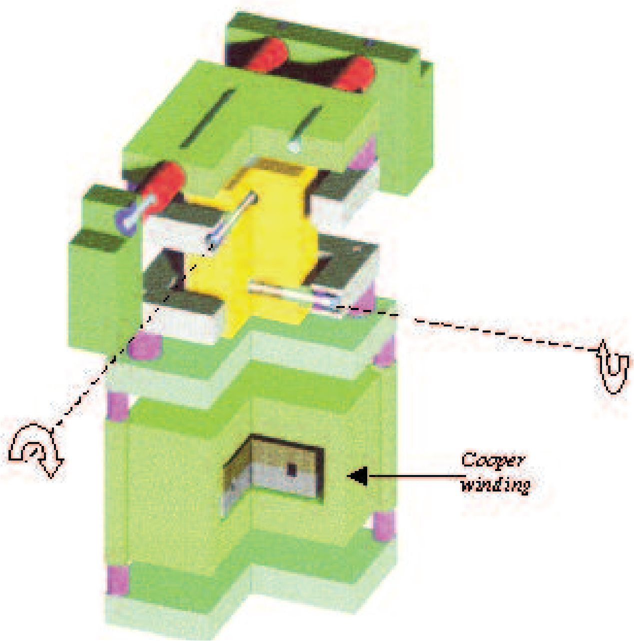

Figure 2. Project of the gimbals of the sensor. One of the two biassial parts of the sensor is visible in the lower part of the figure.

ance.

The two torus size and the choice of the carrying structure, are extremely critical factors. Each torus was realized using a 27 mm diameter aluminum hold on which 10 layers of amorphous material 25 µm wide have been wrapped.

The toroidal sensor linearity depends essentially on the surrounding magnetic field. Therefore in order to minimize the non-linearity error the torus must be constantly immersed in a null field. To realize this condition the nucleus has been surrounded with proper size coils (on a quartz support) in order to create a magnetic field always opposite to the measured one. The measurements of the electric currents in the compensation coils can give preliminary values for the X, Y and Z DC base line current with an error less the 10 nT. In order to check the stability of the vector magnetometer, these values can be used to compare the estimated total intensity of the field (from X, Y and Z) with the intensity measured independently by a proton precession magnetometer. The principal instrumental characteristics are summarized in table I.

3. L'Aquila preliminary test

Magnetic field measurements were conducted for a long period to determine the geo-

Parameter	*Value*
Resolution	50pT
Noise	30 pT/sqr(Hz)
Sensitivity	10 mV/nT
Electronic temperature coefficient	0.007 nT /°C
Sensor temperature coefficient	0.01 nT /°C
Range	1000 nT
Bandwidth	5 Hz
Positioning Error	4”
Sensor Orthogonality Error	0.1°
Compensation Dynamic	10°
Dimension and Weight	26x20x20 cm, 2 Kg
Temperature range	-10°C…40°C

Table I. Characteristics of the autolevelling vectorial magnetometer.

magnetic field transform matrix **A** from the auto levelling magnetometer station to the reference system of the observatory magnetometer. The observatory magnetometer has the same characteristics of the suspended one. The magnetometers were placed 40 km far apart.
The experiment aim was the determination of the nine elements of the geomagnetic field transform matrix **A**.
The elements of this matrix take into account the reciprocal orientation of the two sensors, the non-orthogonality of the axes and the two sensor transfer function differences.

In figure 3 the geomagnetic field components as recorded at the different sites are reported. In figure 4 and 5 the non diagonal elements of **A** when the magnetometers are in the same site and in two different sites are shown respectively. In the ideal case in which the sensors are perfectly aligned, the transfer functions are the same, **A** is an unit matrix. In a more realistic situation, the non diagonal elements of **A** are different from 0 and the diagonal elements are different from 1.

Once the installation of the magnetometers is realized, 120 samples are sufficient in order to define the matrix elements A_{ij} with an error less than the experiment indeterminateness.

The magnetic field H of the suspended magnetometer can be written in the fixed magnetometer coordinate system thanks to **A:**

$$H_x=A_{11}H_{rx}+A_{12}H_{ry}+A_{13}H_{rz}$$
$$H_y=A_{21}H_{rx}+A_{22}H_{ry}+A_{23}H_{rz}$$
$$H_z=A_{31}H_{rx}+A_{32}H_{ry}+A_{33}H_{rz}$$

Where $X_1 \ldots X_n$, $Y_1 \ldots Y_n$ e $Z_1 \ldots Z_n$ are the suspended magnetometer measurements and $X_{r1} \ldots X_{rn}$, $Y_{1r} \ldots Y_{rn}$ e $Z_{r1} \ldots Z_{rn}$ are the observatory magnetometer measurements, n=120 and A_{11}, A_{22} e A_{33} are the diagonal elements of **A**

$$\begin{pmatrix} X_1 \\ X_2 \\ \ldots \\ X_n \end{pmatrix} = \begin{pmatrix} X_{r1} & Y_{r1} & Z_{r1} \\ X_{r2} & Y_{r2} & Z_{r2} \\ \ldots & \ldots & \ldots \\ X_{rn} & Y_{rn} & Z_{rn} \end{pmatrix} \begin{pmatrix} A_{11} \\ A_{12} \\ A_{13} \end{pmatrix}$$

$$\begin{pmatrix} Y_1 \\ Y_2 \\ \ldots \\ Y_n \end{pmatrix} = \begin{pmatrix} X_{r1} & Y_{r1} & Z_{r1} \\ X_{r2} & Y_{r2} & Z_{r2} \\ \ldots & \ldots & \ldots \\ X_{rn} & Y_{rn} & Z_{rn} \end{pmatrix} \begin{pmatrix} A_{31} \\ A_{32} \\ A_{33} \end{pmatrix}$$

$$\begin{pmatrix} Z_1 \\ Z_2 \\ \ldots \\ Z_n \end{pmatrix} = \begin{pmatrix} X_{r1} & Y_{r1} & Z_{r1} \\ X_{r2} & Y_{r2} & Z_{r2} \\ \ldots & \ldots & \ldots \\ X_{rn} & Y_{rn} & Z_{rn} \end{pmatrix} \begin{pmatrix} A_{21} \\ A_{22} \\ A_{23} \end{pmatrix}$$

that in this case are constant. A_{ij} depend on the orientation of the reference frame only in the hypothesis that the geomagnetic field variations

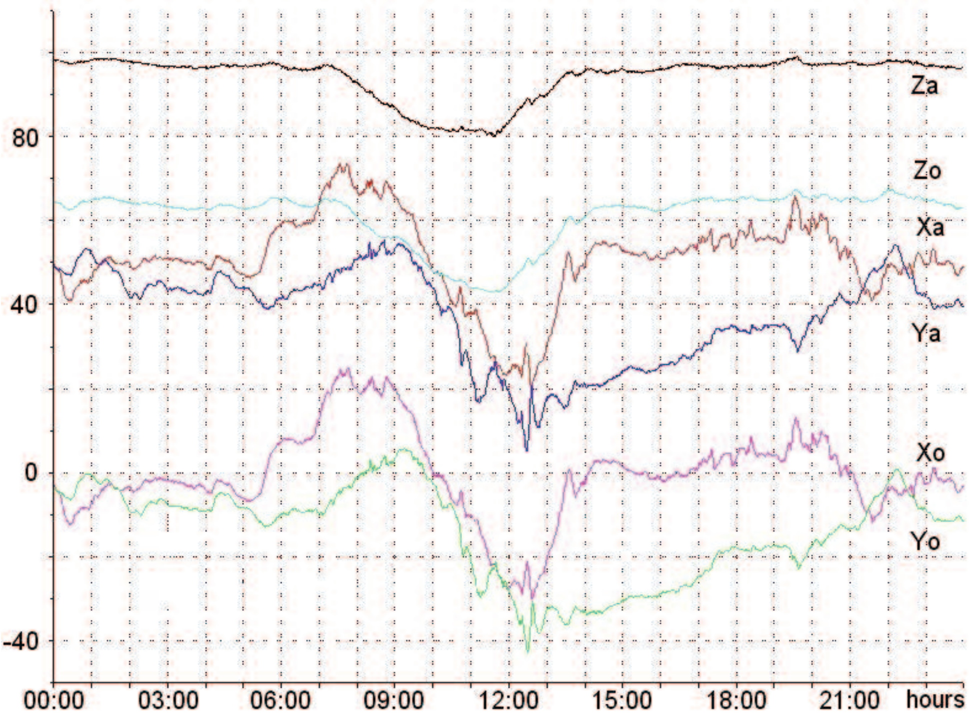

Figure 3. Geomagnetic field component X, Y and Z as recorded in two different sites placed 40 km far apart. In the first site the new autolevelling magnetometer (a in the figure) while in the second site an observatory magnetometer were installed (o in the figure).

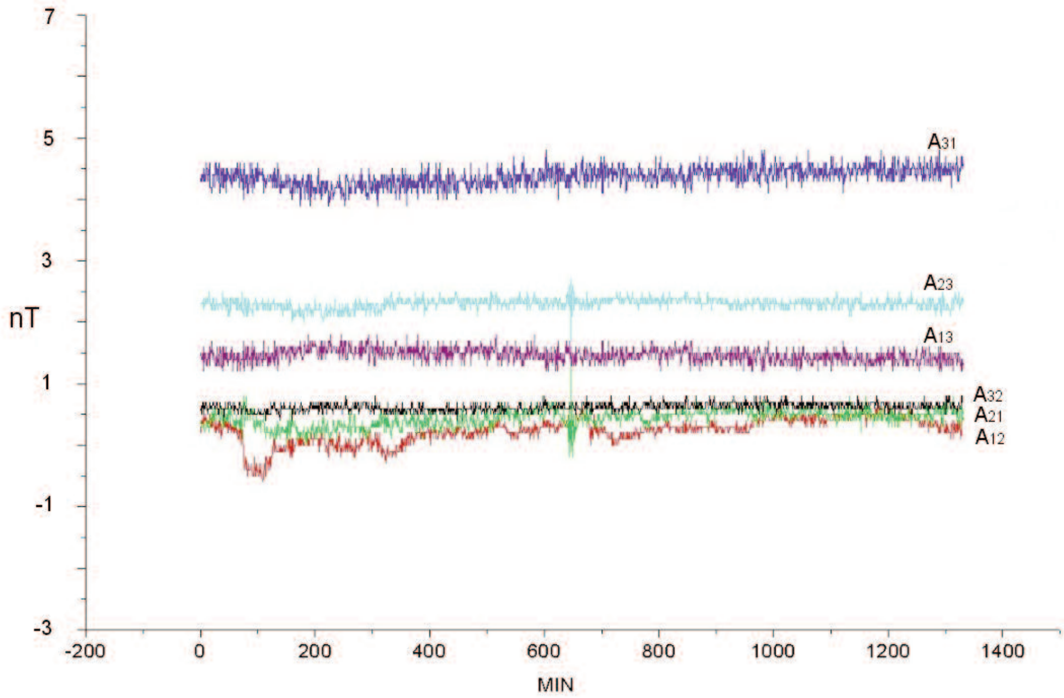

Figure 4. Plot of non-diagonal elements of **A** matrix when the magnetometers are placed in the same site.

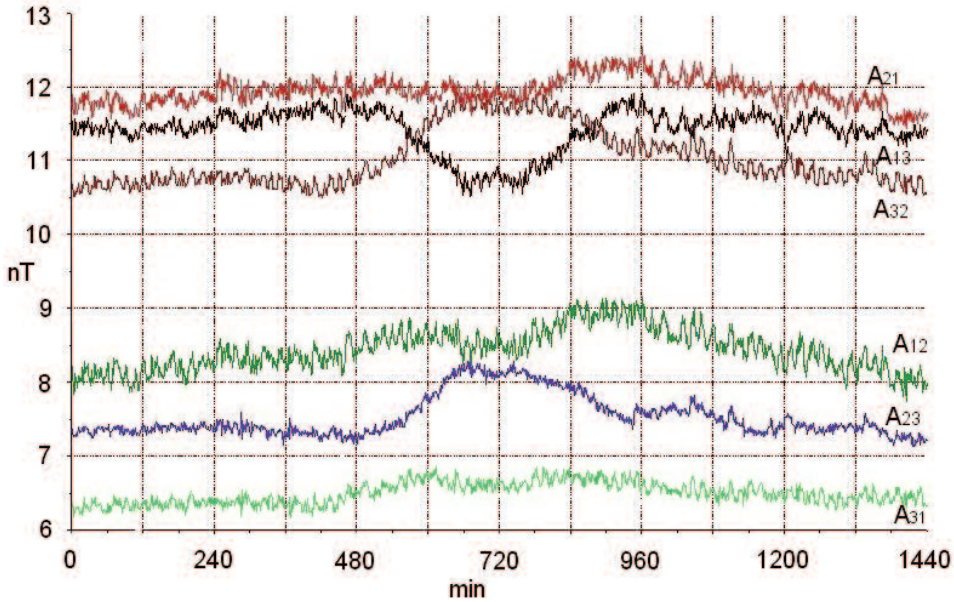

Figure 5. Plot of non-diagonal elements of A matrix when the two magnetometers are placed in two different sites 40 km far apart.

at the two sites are the same. This hypothesis unfortunately is not true if we choose two sites far apart also few kilometers. Necessarily we can find a local geomagnetic field anomalous behaviour using these non diagonal elements only fixing some parameters in the preliminary operations considering that, thanks the magnetometer characteristics, they will not change during the measurements.

In figure 4 and 5 the values of the non diagonal elements are reported: as we can see, they are complex functions depending essentially on the non homogeneity of the geomagnetic field and on inductive phenomena (figure 4: the magnetometers are in the same site, figure 5 the magnetometers are 40 km far apart).

These considerations suggest that the required procedures to evaluate the background noise elements are very laborious also in the simple case in which soil deformations are not present.

4. Conclusions

The magnetometer described in this paper was proposed in order to compensate the movements of the ground in volcanic areas. The sensor was suspended using a compound gimbals while the problem concerning the azimuthal movements of the sensor frame was compensated monitoring the sensor orientation using a remote reference frame (installed far from the volcanic area). The proposed method is based on the determination of the nine geomagnetic field transform matrix elements every 120 minutes. The plots of these parameters can indicate possible local anomalies linked to the geomagnetic filed variations and to ground movements at the reference system. Ground movements (earthquake) at the volcanic station cannot disturb the measured geomagnetic components due to the auto levelling characteristics of the magnetometer.

The characteristics of the anomalies can be defined considering various contributions of the background noise using **A** matrix. The non-diagonal elements of the matrix are complex functions of the anomaly characteristics. The analysis of the factors of a geomagnetic anomalous behaviour can give important information in order to choose a procedure to investigate signals and consequently isolate the anomalies.

Acknowledgements

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