FLUXGATE MAGNETOMETER ARRAY FOR GEOMAGNETIC ABNORMAL PHENOMENA TRACKING

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ABSTRACT

The objective of this project is to develop a flexible observation mode for a geomagnetic abnormal phenomena tracking system. The instrument, based on ring core fluxgate magnetometer technology, improves the field environment performance. Using wireless technology provides on-the-spot mobile networking for the observational data, with efficient access to the earthquake precursor observation network. It provides a powerful detection method for earthquake short-term prediction through installation of a low-noise fluxgate magnetometer array, intensely observing the phenomenon of geomagnetic disturbances and abnormal low-frequency electromagnetic signals in different latitudes, then carrying out observational data processing and exploring the relationship between earthquake activity and geomagnetic field changes.

Keywords: Fluxgate magnetometer, Geomagnetic field, Abnormal tracking, Mobility networking, Field observations, Earthquake precursor

1 INTRODUCTION

In China, geomagnetic monitoring networks are based mainly on large-scale station observation modes with a variety of mobility measurements that obtain observational data through regular artificial measuring. This observation mode is necessary for monitoring the changes in geomagnetic background fields but is insufficient for studying abnormal geomagnetic phenomena. Constructing a mobile tracking system that measures geomagnetic abnormal phenomena would meet the following needs: when earthquakes occur frequently, monitoring the aftershocks; identifying the interference sources of observed abnormal geomagnetic changes; comparing observational equipment in fixed stations; establishing geomagnetic monitoring networks of China’s earthquake background field during the 11th five-year plan, and so on.

The performance of this monitoring instrument is guaranteed to provide high quality data. Compared with Hall magneto-resistance (MR) magnetic sensors and other similar magnetic sensors, the fluxgate magnetic sensor has low cost, simple construction, high sensitivity, and better long-term stability, the primary reasons for its extensive application in ground-based geomagnetic observations (Jankowski & Sucksdorff, 1996; Ripka, 2003; Korepanov et al., 2007). The wireless communication revolution is bringing fundamental changes to data networking and telecommunication and is making integrated networks a reality (Perahia & Stacey, 2008). The observation site using wireless network technology can easily access the monitoring center through on-the-spot mobile networking in the field environment. The tracking system is presented in this paper, including the development of the observation instrument, wireless networking system, requirements for the observation site, and field observation.

2 THE OBSERVATION SYSTEM

2.1 Development of the Observation Instrument

The fluxgate magnetometer is capable of measuring the horizontal, vertical, and declination relative changes of the Earth's magnetic field by simply orienting cores parallel to the desired component. With the support of current technical levels, we have improved the performance of instrument and production processes to adapt to the wild environment.

A sensor with ring cores featuring high sensitivity and a low content of odd harmonics in the magnetizing current in the output is more resistant to mechanical stresses than sensors built around cores of other shapes (Stanislaw, 2006). The ring-core magnetic sensor consists of three windings: exciting, sensing, and
The core, a magnetically sensitive element, is formed by wrapping an alloy frame of high plasticity and endurance strength with a high permeability permalloy strip. It is then given a high-temperature demagnetization treatment.

In the analog signal processing circuit, the excitation of the sensor is produced by a temperature compensated oscillator. The signal from the sensing coil is amplified with a selective frequency amplifier and fed to a phase-sensitive detector, referenced to the second harmonic of the excitation frequency, then amplified again with an integrator. A current proportional to the output voltage is fed back to the sensing winding of the sensor to oppose the field detected by the sensor. Due to amplification and deep negative closed-loop feedback, the sensitivity, stability, and linearity of the magnetometer are high. Using a 24-bit signal conditioning analog-to-digital converter ensures an instrument with a resolution of 0.01nT. The magnetometer achieves automatic compensation through a serial-input, voltage-output, 16-bit digital-to-analog converter (Li & Zhou, 2002).

In order for the host software to develop as a general-purpose operating system platform, the data processing unit adapted an embedded microprocessor and a Linux operating system. A system boot loader program was created; the cutting complier operating system was transplanted into a CPU module, and the relational service software module was configured so that the user is able to design Web pages and applications software based on general operating systems and the high-level programming language. Figure 1 shows the fluxgate sensor and data processing unit.

Considering the particularity of the mobile observation environment, the instrument's power supply, seal, reliability, etc. have been improved, to make it into a low power, portable, simple, easy to install instrument with an enhanced moisture, rain, and vibration protection design.

The performances of the fluxgate magnetometer were calibrated in a magnetic field free space laboratory, the Beijing Baijiatuan Earth Science State Geophysics Observatory, in China. This laboratory created the basic conditions and the necessary environment for the detection and calibration equipment’s performance in geomagnetic observations, development of new magnetic research instruments, and simulated space environment in weak magnetic circumstances (Wang et al., 2008; Auster et al., 2002). Figure 2 show pictures of the magnetic field free space laboratory and experiments during testing.
The magnetometer was calibrated according to the standards of China's Seismic Industry's “Calibration Code for Magnetic Induction of Low Fields.” The performance parameters are shown in Table 1.

Table 1. The performance parameters of fluxgate magnetometer

<table>
<thead>
<tr>
<th>Performance</th>
<th>Parameter</th>
<th>Performance</th>
<th>Parameter</th>
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<tbody>
<tr>
<td>Dynamic range</td>
<td>-2500 nT~ + 2500 nT</td>
<td>Resolution</td>
<td>0.01 nT</td>
</tr>
<tr>
<td>Noise</td>
<td>0.1 nT (p-p)</td>
<td>Linearity</td>
<td>&lt; 5‰ FS</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td>&lt; 1nT/°C</td>
<td>Frequency response</td>
<td>DC~ 0.3Hz</td>
</tr>
<tr>
<td>Sampling</td>
<td>1 second</td>
<td>Power consumption</td>
<td>&lt; 4W</td>
</tr>
<tr>
<td>Sensor size</td>
<td>Ø18cm × 10 cm</td>
<td>Data processing unit size</td>
<td>25.5 cm × 19 cm × 6.5 cm</td>
</tr>
</tbody>
</table>

2.2 The Wireless Networking System

Considering the uncertainty of the observation site and the number of observation instruments, the tracking system adopts a more flexible wireless networking technology to carry out instrument management, registration, and data collection. The management node of the monitoring center is connected to observation instruments by wireless networking, which is deployed with a network management server, application management server, Web server, and related database services. Figure 3 shows the physical topology of the wireless networking system.

1. **Web management server**: deploys basic functions, data collection, alarm, and threshold information that the network management needs, including instrument registration modules and data acquisition modules.
2. **Application management server**: deploys other application modules of the system, including the security and log module, data management module, and alarm processing module.
3. **Web server**: deploys the top level application modules system, which is responsible for user interaction; displays topology information, including the topology generation module, the observation data display module, the troubleshooting configuration module, and so on.
4. **Business database server**: deploys the instrumentation data acquisition of the system database, including the equipment found database, data collection database, and alarm database.
5. **System database server**: deploys the requirement database of upper layer applications and user management information, including the user management database, equipment access database, and so on.
The observational data can effectively access China’s earthquake precursor network by using its wireless network center as a regional center. China’s earthquake precursor network has four levels of network architecture, from a physical and logical viewpoint. The precursor data management network, which covers a subject center, national center, and regional center, and stations form the operation, maintenance, and management system of China’s earthquake precursor network. The user’s right to access is a priority from station to subject center; the main mission of the subject center is to focus on data process and analysis. Figure 4 shows the physical topology of China’s earthquake precursor network.

**Figure 3.** The physical topology of the wireless networking system
2.3 Requirements for the Observation Site

In order to effectively detect the spatial and temporal distribution of space, composition, origin, and application about the main body and around the Earth’s electromagnetic field, geomagnetic observation sites must be free from artificial electromagnetic disturbance above an established tolerance. Therefore the observation environment must meet the maximum electromagnetic interference intensity requirements of environmental noise, magnetic field gradient, and several other sources. Each site must be checked by observing the environment. First, an aeromagnetic map should be used to avoid the magnetic anomalies areas; then a local survey at the surface must be carried out, continuously using a fluxgate magnetometer for 48 hours to record H, Z, and D magnetic component changes, and finally, a magnetic field gradient test must be accomplished using a proton magnetometer. The specific technical requirements are as follows:

1. Event interference less than 2 nT: based on the characteristics of the geomagnetic field, this is the threshold which calculates the peak to peak value of every 10 seconds of observational data.
2. Except for magnetic disturbance by high voltage DC transmission, the intensity of event and short-period magnetic disturbances should be less than 0.1nT p-p between local time 00h ~ 04h.
3. The total magnetic field strength F must have uniform distribution in the observation area 50m × 50m and ΔFh≤5 nT/m.
4. The power supply, communication, and GPS reception conditions.

In field observation practice, to ensure the operation’s temperature environment and long-term stability, the observation instruments are installed underground. Figure 5 shows the schematic diagram of a typical setup for an observation instrument.
Figure 5. The schematic diagram of a typical observation instrument set up
The fluxgate sensor and data processing unit are buried under the permafrost layer. The advantage of this method is that it reduces the influence of sunlight on the observational temperature and guarantees the observational environment temperature to be above freezing, especially during the winter. The pillar is placed in deep soil for long-term stability.

3 FIELD OBSERVATIONS

For the purpose of monitoring and identifying any possible electromagnetic precursors before earthquakes, two tracking systems of geomagnetic arrays were built by China’s Earthquake Administration. These include 18 magnetic sites equipped with tri-axial fluxgate magnetometers of 1s sampling rate near the seismically active regions in the Sichuan and Gansu Provinces, respectively. Figures 6, 7, and 8 show the observation wave of D, H, and Z components in the Sichuan geomagnetic arrays. Figure 9 shows the geomagnetic daily variation wave at one site.

Figure 6. The observation wave of the D component in Sichuan geomagnetic arrays
Figure 7. The observation wave of the H component in Sichuan geomagnetic arrays

Figure 8. The observation wave of the Z component in Sichuan geomagnetic arrays
Figure 9. The geomagnetic daily variation wave of one site

Different geomagnetic events own special frequency spectrum ranges. These can be used to identify and extract characteristic information about the geomagnetic events, such as magnetic storms, pulsations, and so on. Figure 10 shows a Pc3 magnetic pulsation recorded at the Shitan, Hongshawan, and Huangyangchuan sites.

Figure 10. The Pc3 geomagnetic pulsation recorded at the Shitan, Hongshawan, and Huangyangchuan sites, respectively
4 CONCLUSION

The combination of simple buried installation, data processing, and intensive measuring of sites is an effective method of geomagnetic measuring that has obtained a great deal of raw data over long-term field observations. The components and key technology of this tracking system are presented. The average distance of a fluxgate array in a site is about 50Km. This can provide geomagnetic field signals of frequencies from 0.3Hz to DC and resolution 0.01nT, including a lithospheric magnetic field, an ionosphere magnetic field, a magnetosphere magnetic field, and an induced magnetic field within the solid Earth. With development of the practical study of the relationship between earthquakes and magnetism, it is possible that mobile geomagnetic arrays can be used for short-term earthquake tracking.

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6 REFERENCES


