DESCRIPTION OF AND RESULTS FROM A NOVEL DIRECT MAGNETIC GRADIOMETER

Howard Golden
Gravitec Instruments Ltd
140 Colin St
West Perth WA 6005
Australia
howardgolden@gravitec.co.nz

Wayne McRae
Gravitec Instruments Ltd
140 Colin St
West Perth WA 6005
Australia
wayne@gravitec.co.nz

Andrew Sunderland
The University of Western Australia
School of Physics M013
35 Stirling Highway
Crawley WA 6009
Australia
asund@physics.uwa.edu.au

Alexey Veryaskin
Gravitec Instruments Ltd
140 Colin St
West Perth WA 6005
Australia
a.v.veryaskin@gravitec.co.nz

Ju Li
The University of Western Australia
School of Physics M013
35 Stirling Highway
Crawley WA 6009
Australia
asund@physics.uwa.edu.au

David G. Blair
The University of Western Australia
School of Physics M013
35 Stirling Highway
Crawley WA 6009
Australia
asund@physics.uwa.edu.au

SUMMARY

Gravitec Instruments is continuing work on a novel direct magnetic gradiometer for use in mobile and static mineral surveying. The compact, robust design lends itself to airborne and borehole deployment and could be used in other applications where space and power are strictly limited. Results from recent testing will be discussed.

Key words: Magnetic Gradiometer, Airborne, Mineral Surveying, Amati

INTRODUCTION

Nearly all magnetic gradiometers in use utilise two magnetometers, separated along a base line, differencing a measured total magnetic field. Taking the difference in the magnetic field strength at those two locations gives an estimate of the magnetic gradient. Difficulties in cancelling out the huge magnetic field of the Earth (30000 – 50000 nT compared to gradients signals measured in nT/m) and aligning the sensitivity axis of two magnetometers limit the sensitivity of these devices. In contrast, the sensor being developed by Gravitec uses a single sensitive element to directly measure the magnetic gradient and is immune to the much larger uniform field of the Earth.

The sensor is being tested in the laboratory and at a field testing site to determine the sensor noise floor and to measure the geologically induced local gradient near Perth, Australia. The advantages of measuring magnetic gradient tensor over the more conventional total magnetic intensity measurement are many, and are discussed in depth by Schmidt and Clark (2000).

METHOD AND RESULTS

Project AMATI, so named in honour of the famous violin maker Nicolo Amati, is focussed on developing a direct string Magnetic Gradiometer capable of measuring cross-diagonal components of the magnetic gradient tensor (Veryaskin, 2000; Veryaskin, 2001; McRae *et. al.*, 2004). The device, being developed by Gravitec Instruments in conjunction with The University of Western Australia, employs a single vibrating string as the sensing element. The system operates at the string's 2nd violin mode at about 850 Hz. This 2nd violin mode is only sensitive to gradients, whilst the 1st fundamental mode couples with the uniform magnetic field.

The basic operational principle of the sensor is to measure the deflection of a current carrying wire in the presence of the Earth's magnetic field. In order to differentiate between the uniform field of the Earth and the more useful gradient field produced by variations in magnetic minerals local to the sensor, we 'select' for deflections caused by a varying magnetic field along the length of the sensing element. This is achieved by driving the string using an AC current at the second harmonic frequency of the string. The force from a uniform magnetic field would deflect the string in its fundamental mode (minima at the ends where the string is clamped and maximum at the centre). In contrast, the force from the gradient field would deflect the string in its second order mode. Since we are driving the string at the second harmonic frequency, the string oscillates at the second harmonic due solely to the gradient field local to the sensor.

The displacement of the string can be measured with two inductive pickup coils, connected in differential mode, placed close to the string, one quarter and three quarters along the length of the string respectively. The signals from the inductive pickups are sent to a low noise pre-amp located about 2 m from the sensor head. A cable connects the pre-amp unit to a digital signal processing unit which actively monitors the signal and transfers data to a nearby laptop. The cabling distance ensures the electronics or towing platform do not interfere with the sensor or produce any detectable local gradients.

Currently the sensor noise floor is approximately 50 pT/m below 0.1 Hz while averaging the signal over 1 second in an unshielded environment (see Figure 1). Work is continuing to increase the sensitivity noise floor down to at least 20 pT/m and to reduce the local magnetic heading error of the system.

The string operates as a part of a PID feedback loop wherein the effective magnetic gradient acting upon it is locked to a constant value. This in turn allowed implementation of a built-in string frequency tracking algorithm, where the real-time string resonant frequency is monitored and the string drive frequency is locked to the real-time frequency.

The instrument operates with a common mode rejection ratio of about 10^7 at room temperature, and is isolated from vibration by a three stage passive isolator developed at the University of Western Australia. The isolator, developed specifically for the Gravitec Magnetic Gradiometer, damps vibration at the frequency used by the string by approximately 100 dB. The isolator and sensor are evacuated to eliminate the effect of external acoustic noise.

Figure 1. A Magnetic Gradiometer sensor mounted inside a 3-stage passive isolator. The sensor itself is 300 mm × 30 mm × 30 mm and weights 200 g. It operates at room temperature in either atmospheric pressure or vacuum. The suspension is employed to provide 3-stage isolation of the sensor from aircraft acoustic and vibration noise.

The current mechanical design of the Magnetic Gradiometer sensor head has been constructed in order to reduce potential heading error associated with self magnetisation caused by ferrous metal parts and electronic components inside the sensor frame. Currently the entire assembly is made of a solid plastic with thermal expansion coefficient that precisely matches that of the string material. The round string used in Gravitec's previous design has been replaced with a flat (ribbon) wire having a smaller mass per unit length. This allows the sensor to have a well defined sensitivity in the axis of the measured gradient and remove any interference from unwanted mechanical degrees of freedom that exist in the case of a round wire.

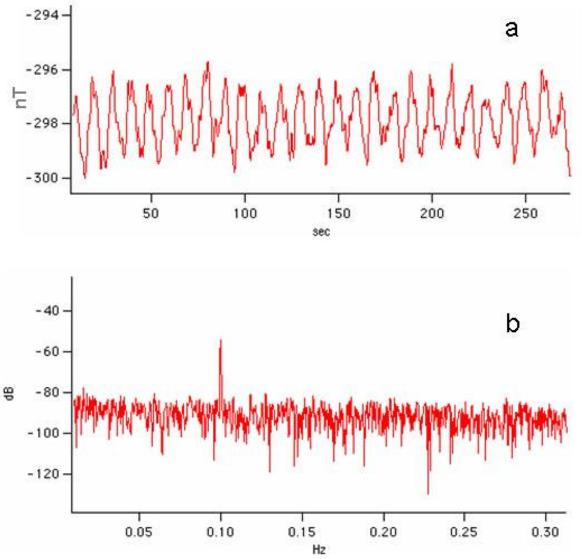

Figure 2. Time domain (a) and spectral data (b) recorded from the Magnetic Gradiometer. A magnetic gradient signal of 1.6 nT/m peak at 0.1 Hz is used to determine the sensitivity of the sensor. The noise floor is about 50 pT/m below 0.1 Hz with the cut-off frequency determined by 1 sec integration time. The gradiometer was stationary in an unshielded environment. The raw data has not been improved by removing the DC component in the frequency domain.

In Figure 3 we compare the response of a Caesium vapour magnetometer to the string Magnetic Gradiometer. The magnetometer was moved along a 20 m profile with measurements taken at 1 m intervals. The survey line was centred on a high frequency highly magnetic anomaly. The nature of the anomaly is unknown, though it is suspected to be a small man-made object shallowly buried beneath the surface. This provides a large magnetic field and magnetic gradient, especially close to the site of the object. The caesium vapour magnetometer struggled to lock on measurements close to the anomaly; at those sites several attempts were required to obtain the measurement.

The gradient was calculated from the magnetometer data by differencing the readings at adjacent locations. This is similar to the method that would be used in standard Magnetic Gradiometers composed of two matched magnetometers. We repeated the survey with the string Magnetic Gradiometer, 1 m spacing over the same 20 m survey line. The string magnetic was able to resolve more detail than was possible from the magnetometer.

The field and laboratory measurements are approaching the stage where the system will soon be deemed sensitive and robust enough for testing in a vehicle such as a helicopter.

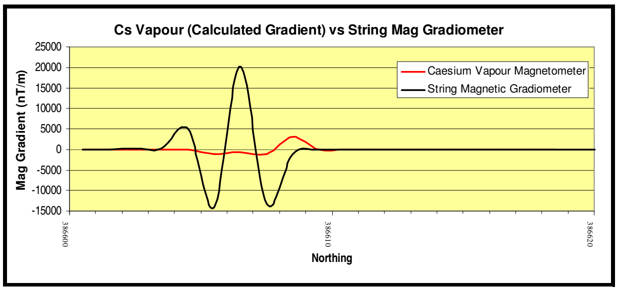

Figure 3. Comparison between the measurements from a Caesium vapour magnetometer and the string gradiometer over a large shallow magnetic anomaly buried beneath the surface. The measurements from the magnetometer were differenced to produce a horizontal magnetic gradient, allowing better comparison. Due to the magnitude of the gradient, the magnetometer had trouble acquiring the measurement close to the anomaly. The string gradiometer was able to measure the gradient at all points along the survey line.

The work to date on the Magnetic Gradiometer has been intended to produce a system suitable for airborne use, but recent interest could lead to the sensor being packaged for static ground and mineral borehole use. The similarities between Gravitec's Magnetic Gradiometer and ribbon Gravity Gradiometer systems mean that work on the borehole gravity gradiometer system is complimentary with the ongoing work on the Magnetic Gradiometer system.

CONCLUSIONS

Field testing has shown that Gravitec's Magnetic Gradiometer is capable of measuring magnetic gradients as small as 50 pT.m in the 0.01 Hz to 0.3 Hz frequency range. Work is progressing on increasing this sensitivity to at least 20 pT/m. Once packaged for use in aircraft, static ground, and boreholes the sensor will provide useful Magnetic Gradiometer data in a robust, low cost tool.

REFERENCES

Schmidt, P.W. and D.A. Clark, 2000, Advantages of measuring the magnetic gradient tensor: Preview, 85, p. 26-30.

McRae, Wayne M., Veryaskin, Alexey V., Ju, Li, Blair, David G., Chin, Eu-Jeen, Dumas, Jean-Charles, and Lee, Ben, 2004, String magnetic gradiometer system: recent airborne trials: SEG Technical Program Expanded Abstracts, pp. 790-793.

Veryaskin, Alexey V., 2000, A novel combined gravity & magnetic gradiometer system for mobile applications: SEG Technical Program Expanded Abstracts, pp. 420-423.

Veryaskin, Aeryaskin V., 2001, Magnetic Gradiometery: a new method for magnetic gradient measurements: Sensors and Actuators A, 91, 233-235.