Compensation of SQUID gradient data in a magnetic tensor gradiometer system for airborne exploration

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Aeromagnetic exploration is an important prospecting method in geophysics. Starting in 1997, a SQUID based gradiometer system has been developed, which makes it possible to directly measure the gradient tensor components and has many advantages compared to conventional TMI measurements. Meanwhile, questions have been raised about the compensation due to its high sensitivity. Therefore, the aeromagnetic compensation method urgently needs improvement.

The main interference source of noise to a single gradiometer can be classified into two distinct groups. The first group is the interference from the gradiometer itself, including the scaling factor from the magnitude of the magnetic gradient field component to the corresponding sensor signal (s) and the offsets of the gradiometers ($o1$). In addition, the inherent parasitic response in the gradiometers to the corresponding magnetic field, which is due to fabrication limitation of the SQUID gradiometer, should also be re-processed. This procedure is usually called balancing. The second group is the magnetic noise external to the gradiometer, whose major component is related to maneuvers of the mobile platform. In the common aeromagnetic compensation model, the interference fields generated by the platform can be grouped into three types: permanent, induced, and eddy-current magnetic fields (Leliak 1961). Because the tow rope is long enough, we mainly consider the external magnetic sources in the bird, whose relative position to the sensors are fixed during a long run. Therefore, the permanent magnetic field is a constant for a sensor ($o2$). Furthermore, the magnetic moments of the induced or eddy-current magnetic field are proportional to the geomagnetic background field or its time derivative in the measurement coordination system ($\mathbf{H}_e$, $d\mathbf{H}_e$) respectively, which can be given as:

$$\mathbf{M}_{ind}\left(\mathbf{H}_e\right)=\left(k_x H_{ex}, k_y H_{ey}, k_z H_{ez}\right),$$
$$\mathbf{M}_v\left(d\mathbf{H}_e\right)=\left(e_x dH_{ex}, e_y dH_{ey}, e_z dH_{ez}\right).$$

Therefore, we present a new compensation model for a single gradiometer in the measurement coordination system based on the aforementioned interference sources:

$$\begin{aligned} G_m &= sG + o1 + o2 + G_{out}^{l} + G_{balance}^{l} + n \\ &= sG + o + \tilde{g}_0\left(\sum_{i=-p}^{p}\mathbf{H}_e\left(t-i/fs\right)\right) + \tilde{g}_1\left(\sum_{i=-p}^{p} d\mathbf{H}_e\left(t-i/fs\right)\right) + h_0\left(\sum_{i=-q}^{q}\mathbf{B}_r\left(t-i/fs\right)\right) + n \end{aligned} \tag{1}$$

$$\begin{aligned} G &= \frac{1}{s}\left(G_m - o - \tilde{g}_0\left(\sum_{i=-p}^{p}\mathbf{H}_e\left(t-i/fs\right)\right) - \tilde{g}_1\left(\sum_{i=-p}^{p} d\mathbf{H}_e\left(t-i/fs\right)\right) - h_0\left(\sum_{i=-q}^{q}\mathbf{B}_r\left(t-i/fs\right)\right)\right) \\ &\doteq s1G_m^{l} - so1 - \sum_{i=-p,j=x}^{i=p,j=z} a_{i+p+1,j} H_{ej}\left(t-i/fs\right) - \sum_{i=-p,j=x}^{i=p,j=z} b_{i+p+1,j}\, dH_{ej}\left(t-i/fs\right) - \sum_{i=-q,j=x}^{i=p,j=z} c_{i+p+1,j} B_{rj}\left(t-i/fs\right) \end{aligned} \tag{2}$$

where the fifth item is used for balancing and removing induced noise in the area with local magnetic anomalies. The last three items are used as linear filter for processing asynchronous of the different sensors in the system. There are M=12p+6q+11 compensation coefficients in this model, and they can be calculated by ridge regression or the PCA method. By putting the compensation coefficients back into Eq.

(2), the compensated gradient data will be gained. It should also be noted that a single processing step is not enough to obtain dependable data for geophysical application. The main processing steps for raw system data also contain the calibration of the reference vector magnetometers and data filtering.

To demonstrate the availability of the presented method, we provide the compensation result for one of gradiometer channels, as shown in Figure 1. This indicates that the compensation algorithm is very effective at low frequencies. RMS and IR of the compensation result are also good enough (RMS=1.61e-2, IR=2.35e3).

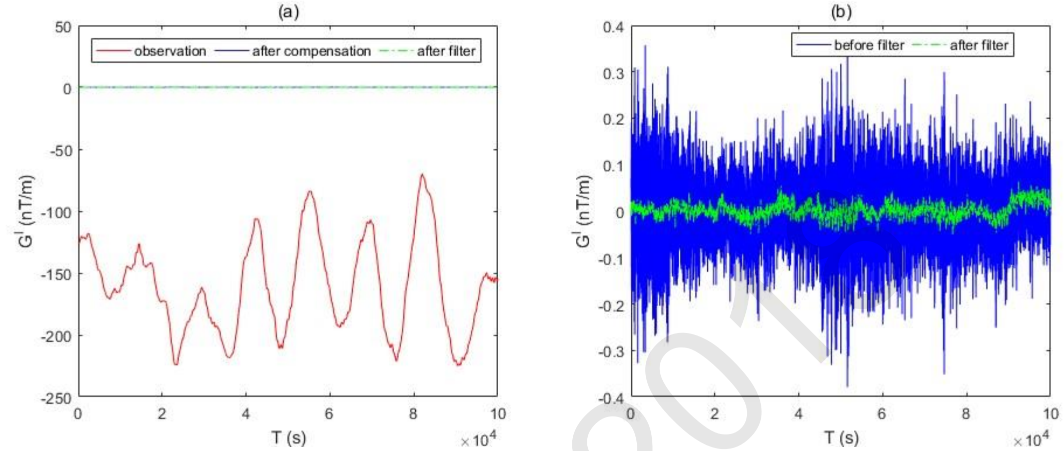

Figure 1. Comparison of raw gradiometer data (red), compensated gradiometer data (blue) and low-pass filtering data after composition (green).