IMPROVED LOW MAGNETIC FIELD MEASUREMENTS

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Introduction

The ongoing interest in the effects of magnetic fields on health mean that the calibration of coil systems and instruments which measure low level magnetic fields, at frequencies from DC to 120 kHz, continues to be an area of increasing demand. At NPL work continues on improving traceable measurement methods for instruments and coil systems in this range. Further development of the triaxial Helmholtz coil system and its associated servo system has improved the uniformity and stability of the volume of cancelled ambient field. This has allowed improvements in the calibration of Helmholtz coils and solenoids, and uncertainties as low as 0.015% have been achieved using a proton resonance magnetometer method.

Low magnetic field facility

The low magnetic field facility was set up in a room in Bushy House, which was chosen because of the low magnetic field gradient and ambient AC magnetic field [1]. This room contains a triaxial Helmholtz coil system of 3 m diameter, through the coils of which currents are passed which are controlled by the output from a remote three axis fluxgate magnetometer. This allows cancellation of the ambient magnetic field to better than 1 nT at the centre of the coils.

Despite the low magnetic field gradient of the room of around 15 nT/m [1], the 150 mm cube at the centre of the triaxial Helmholtz coil system was found to have a maximum deviation from the value at the centre of 7 nT. Significant magnetic field gradients were observed parallel to the north-south and east-west axes. The vertical direction had a more complicated pattern, with a higher gradient in the north east corner of the cube than in the south west. To reduce these gradients one of each Helmholtz pair was wound with an extra turn. Currents for this extra coil were obtained from the main winding current using a shunt, except for the east-west axis where the main coil current was insufficient and it was necessary to use a DC supply.

By careful adjustment of the current flowing in these extra turns it was possible to reduce the non-uniformity in the north-south and east-west axes to less than 1 nT. This improved the overall uniformity to around 4 nT for the 150 mm cube, as shown in Figure 1. The majority of the non-uniformity is in the lower north east corner and so within a 150 mm sphere the uniformity is around 2 nT.

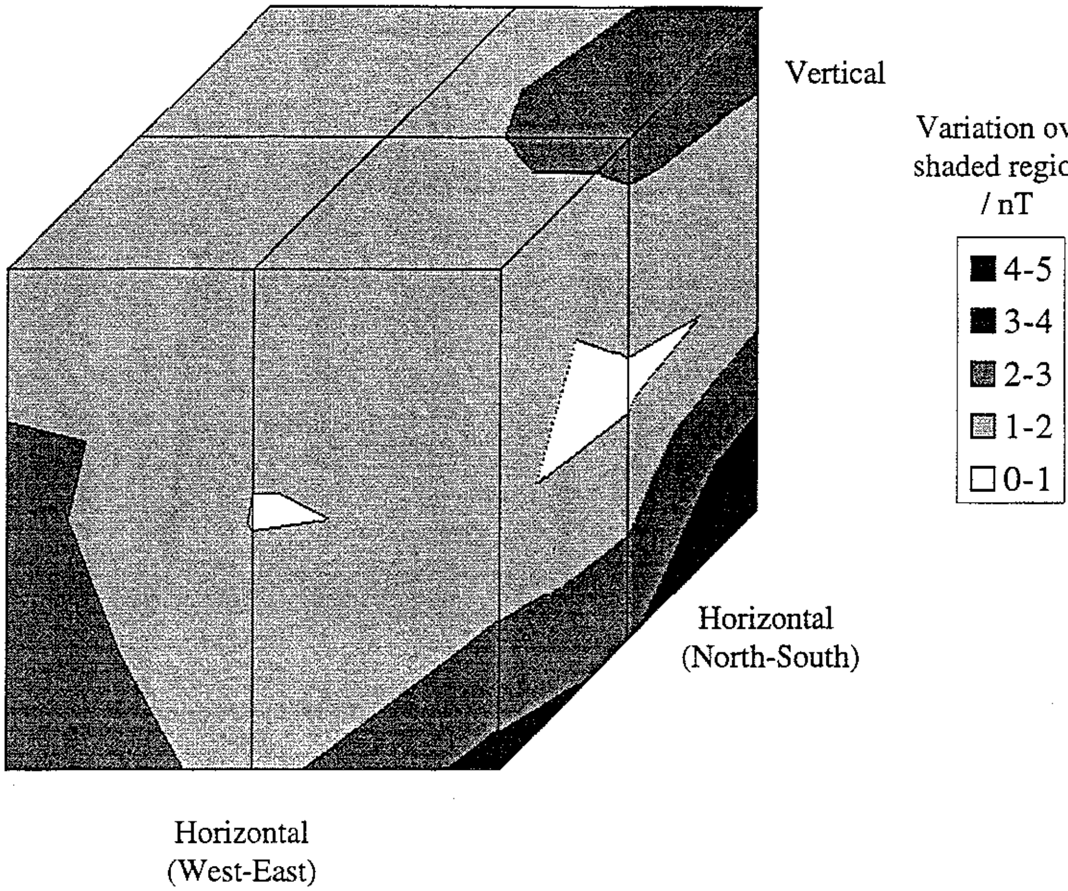

Figure 1 - Uniformity of Triaxial Helmholtz coil system.

Calibration of Helmholtz coils

The improved performance of the cancellation system has allowed much improved calibration of Helmholtz coil systems. The coils can now be calibrated for their magnetic field strength to current constant by measuring the field produced using a proton resonance magnetometer.

The proton resonance magnetometer measures the resonant frequency of the protons in a fluid. This is related to the applied flux density by the gyromagnetic ratio of the proton. The proton resonance magnetometer is a total field sensing device with a resolution of 0.1 nT, and a range of 20 μT to 90 μT. To achieve maximum resolution the instrument requires a magnetic field uniform over the probe volume and stable during the measurement period.

By placing the proton resonance magnetometer probe and the coil to be calibrated inside the triaxial Helmholtz coil system sufficient stability and uniformity of magnetic field can be obtained to maximise resolution and repeatability. Cancelling out the ambient magnetic field allows magnetic field strength to current ratio measurements to be made at a number of applied field levels spanning the range of the magnetometer. The magnetic field strength to current ratio of the coil system should be independent of field strength as non magnetic materials were used in its construction.

The method of measurement is to place the Helmholtz coils or solenoid to be calibrated in the centre of the triaxial Helmholtz coil system. The cancellation system is then used to reduce the total field at the centre of the triaxial Helmholtz coil system to as near zero as possible. The magnetic field at the centre is measured using a triaxial fluxgate magnetometer; typically the field can be reduced to around 0.5 nT. The fluxgate magnetometer is then removed and replaced by the proton resonance magnetometer.

A measured current is passed through the windings of the coil system being calibrated and the reading of the proton resonance magnetometer taken. A series of measurements are made, reversing the current in the coils between each one, thereby reducing the effect of any residual field along the coil axis. Any small residual fields measured at right angles to the coil axis will add to the magnetometer reading by a square root of the sum of the squares (RSS) method and will therefore be negligible. Finally the fluxgate magnetometer is replaced and any drift in the cancellation system noted. From the readings of the proton resonance magnetometer and the current passing through the coil the magnetic field strength to current ratio of the coils can be calculated.

The uncertainty of the magnetic flux density sensed by the proton resonance probe is limited by the resolution of the proton resonance magnetometer to 0.1 nT. In most Helmholtz coil systems a correction needs to be applied for the non-uniformity of the field produced by the Helmholtz coils over the volume of the probe, which is a 12 cm long cylinder of 10 cm diameter. The uncertainty in this correction becomes significant for small diameter coil systems.

For one coil system this method gives an uncertainty of 0.015%, compared to around 0.1% using previous methods. For other coils measured the reduction in uncertainty has been smaller but still significant.

References

[1] Rollett, D A, and Drake, A E, "Traceable magnetic field strength measurements to 120 kHz", IEE Proc.-Sci. Meas. Technol., Vol. 143, No 4, pp.255-258, July 1996.

Acknowledgement

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