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Properties of a thick-walled conducting enclosure in low-frequency magnetic shielding

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Abstract We have constructed a thick-walled aluminium shield for biomagnetic measurements and measured its performance at 50 Hz in detail. This data shows the difficulties in the construction of the door. The mechanical vibration is attenuated efficiently. The benefits of an aluminium shield in cost and construction over the μ-metal shield are discussed.

1 Introduction

The growing interest in biomagnetic research has increased the need of magnetically shielded enclosures. The biomagnetic signals have the amplitude of the order of 10^{-10} T for the magnetocardiogram and 10^{-12} T for the magnetoencephalogram within the frequency band of 1 to 100 Hz. The noise level in ordinary laboratories is of the order of 10^{-8} T within the biomagnetic frequency band. A satisfactory recording of biomagnetic signals in such an environment is possible when using a differential magnetometer or effective magnetic shielding.

Magnetic shielding is possible to accomplish in three ways: using magnetically highly permeable material, thick-walled conducting shield or active compensation. The best result is achieved when combining these methods (Cohen 1970). Almost all magnetically shielded enclosures are constructed primarily from magnetically permeable μ-metal. This method is applicable from DC to radio-frequencies. The main disadvantages in the use of μ-metal are its sensitivity to mechanical vibration, loss of permeability in mechanical stress, which makes the construction difficult and high price.

Zimmerman described a method of constructing the magnetically shielded enclosure from thick-walled conducting material (Zimmerman 1977). The benefits in its use are low price and easy and rigid construction. Its main disadvantage is that the attenuation provided by the shield is an increasing function of frequency and is zero for a static field.

We have constructed a thick-walled aluminium shield and measured its attenuation. In this paper we present the results from our measurements.

2 Theoretical attenuation properties of a conducting shield

Zimmerman approximates the shield with a long tube and calculates the field inside the shield to be

$$H = H_{\mathrm{ex}}(\omega)\, 1/(1 + j\omega\tau) \qquad (1)$$

where

$$\tau = \frac{\mu_0 \sigma w h t}{2(w+h)} \qquad (2)$$

and

ω = angular frequency
μ_0 = magnetic permability of free space
σ = conductivity
h = height
w = width
t = wall thickness.

The time constant τ characterises the response to a uniform applied field.

If the conductivity of the aluminium wall is 36×10^6 S m^{-1}, its thickness is 0·045 m and the dimensions of the enclosure are $2 \times 2 \times 2$ m the time constant τ equals 1·02 s and the attenuation is 50 dB at 50 Hz. This value applies for a closed shield without door.

3 The shield

Our shield is constructed from 45 mm thick aluminium plate by welding the seams completely through the plate. The material is 99·5% pure aluminium with conductivity 36×10^6 S m^{-1}. The outer dimensions of the shield are $2 \times 2 \times 2$ m. It has a 545 mm wide doorway on the side of one wall. To decrease the loss of attenuation due to the door a 795 mm long corridor is constructed inside the shield, figure 1. The total weight of the shield is approximately 3000 kg.

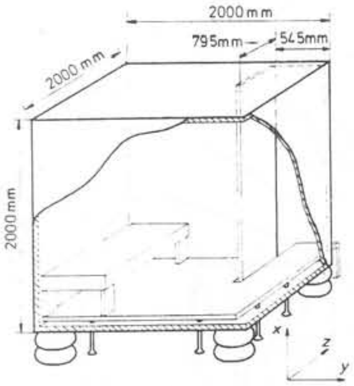

Figure 1 The shield is constructed from 45 mm thick aluminium plate.

Because the shield gives no attenuation for the earth's static field the mechanical movement of the detector may induce considerable noise Therefore it is important to attenuate the mechanical vibration of the shield. To attenuate the mechanical vibration caused by the building, the shield is mounted on four pneumatic dampers. To attenuate the vibrations caused by the personnel inside the shield, the shield is equipped with a plywood floor which stands on the laboratory floor on brass rods through holes in the bottom of the shield.

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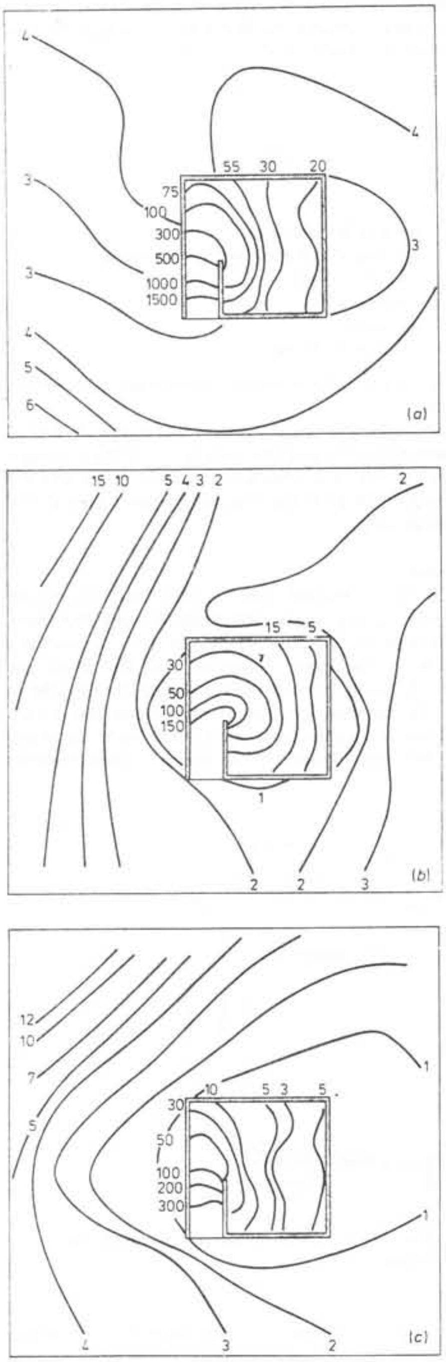

Figure 2 The RMS values of the three orthogonal components of the 50 Hz magnetic field in the laboratory outside and inside the shield. The dimensions are in nT outside the shield and in pT inside the shield. (*a*), x component; (*b*), y component; (*c*) z component of the magnetic field.

4 The measurements

The measurements were performed with a system composing of a coil, an amplifier, and a spectrum analyser. The inner and outer diameters of the coil were 97 and 148 mm, its thickness was 31 mm, and it had 2000 turns of 0·5 mm copper wire. The effective area of the coil was calculated to be 23·6 m^2, and it was covered with a thin aluminium foil to shield it against electric field.

The amplifier was Princeton Applied Research Model 113 Pre. Amp. equipped with a low noise impedance transformer. The signal was analysed with Honeywell, Saicor spectrum analyser Model SAI 51B.

The three orthogonal measurements of the magnetic field were performed outside the shield in 70 points at distances from 200 to 1500 mm from the wall at 1 m height from the shield floor. Inside the shield the measurements were performed at 100 points, all at 1 metre height. The distance between these points was 200 mm.

From the induced 50 Hz voltage we calculated the spatial magnetic flux density. Its temporal variation was corrected according to the voltage of a reference coil located outside the shield.

The field strength in the laboratory varies from 5 nT to 15 nT during the day. The noise reaches the minimum level at night, when the building is silent. About 30% of the magnetic field is caused by the electric power lines outside the building. This was verified by disconnecting all electric power to the building.

The attenuation of the magnetic 50 Hz field inside the shield is presented in figure 2, for each component. The field strengths are given in RMS values and the dimensions are in nanoteslas outside the shield and in picoteslas inside the shield. The maximum attenuation of the shield is 44 dB in x direction, 46 dB in y direction and 50 dB z direction with 50 Hz field.

5 Discussion

The shield seems to achieve the full theoretical attenuation of 50 dB in only one component of the magnetic field. In all three orthogonal directions at least 40 dB attenuation is achieved in about half of the enclosures area. This indicates that the doorway is an important question in designing magnetically shielded enclosures. In our shield the doorway leaks magnetic field so much that the experimental area is small though the maximum theoretical attenuation is achieved. The leakage could be diminished by extending the corridor. This should be done outwards to keep the experimental area large enough.

Another important improvement would be to equip the shield with an active compensation with Helmholtz coils. The compensation of the earth's static field improves the noise rejection because the mechanical vibration would induce less noise though the present pneumatic damping system is very effective. It is also possible to equip the Helmholtz coil system with a magnetic field detector and an amplifier and to compensate the low frequency magnetic fields and thus further improve the noise rejection.

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