New Six-Layer Magnetically-Shielded Room for MEG

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Abstract

A high performance magnetically-shielded room (MSR) has been built by Imedco, to house a 4-D MEG system, containing both gradiometers and magnetometers (Vectorview™). The MSR consists of three nested enclosures, each consisting of a high-permeability magnetic layer plus an aluminum layer, where special care was given to the junctions of the inner aluminum layer. Measurements of the passive shielding factor yield 1,630 (64dB), 3,600 (71dB), 240,000 (107dB) , and 78,000,000 (158dB) at frequencies of 0.01 Hz, 0.10 Hz, 1.0 Hz, and 10 Hz respectively. Thus, our room is among the very good MSRs. In addition, an active system is being developed, now yielding an extra SF of 6-10 at 0.10 Hz; this needs improvement to reduce new electric train disturbances. Also, we plan to reduce disturbances generated by the inner high-permeability layer when it is mechanically perturbed, for example by walking in the room.

1 Introduction

A complete MEG facility has been added to the Athinoula A. Martinos Center for Biomedical Imaging, which is a satellite research site of the Dept. of Radiology of the Massachusetts General Hospital (MGH). It is located in Charlestown, about one km from the main MGH and downtown Boston. The Center already employs a variety of brain imaging technologies including MRI, fMRI, EEG, and optical imaging, and the addition of MEG allows another degree of multi-modal brain imaging. The core of the new MEG facility is a magnetically-shielded room (MSR) containing a whole-head MEG detection system. The MSR was built by Imedco AG, of Hägendorf, Switzerland; they originally proposed the design, and after some suggested design changes, first pre-assembled the MSR at their factory. The MEG system is a 306-channel Vectorview™ built by 4-D Neuroimaging, containing 204 planar gradiometers and 102 magnetometers. Our purpose here is to describe the MSR, and report on its present performance and planned improvements.

2 Design Criteria

When originally mapped, several years ago, the MSR site was magnetically quiet, with a background noise of about $20nT_{pp}$ weighted heavily with frequencies well below 1 Hz. This was mostly of the horizontal component, produced by elevators in the building, and by external road vehicles; there was no evidence of a vertical component usually produced by electric trains, where the closest train approach is ~1.3 km. With this information, the shielding factor (SF, the ratio of external to internal field) of the MSR was chosen to be ≥78 dB (8000) at 0.010 Hz, which was enough shielding so the background would not be seen at all by the gradiometers, but would indeed be seen at a modest level by the magnetometers. This level would be about 6 times intrinsic SQUID noise, which is ~30 fT/√Hz at the low frequencies typical of this back-ground noise, in the range of 0.010 to 0.10 Hz. The ≥78 dB was to combine ≥58 dB of passive shielding with 20 dB of active shielding. However, as we explain below, the background vertical noise has recently increased significantly, thereby putting a greater burden on the active system.

3 Main Construction Features

The MSR consists of three nested main layers, as shown in Fig.1. Each of the these layers in turn is made of a pure aluminum layer plus a high permeability ferromagnetic layer, which is Magnifer 7904 MP200 (Krupp), similar in composition to Moly Permalloy. This Magnifer is supplied as 1 mm sheets; the inner layer is composed of four sheets in close contact, and the outer two layers of three sheets

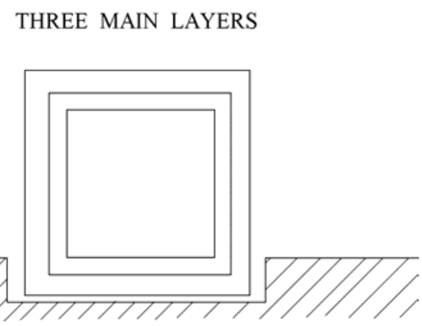

Figure 1. External dimensions: 4.1m high, 4.3m wide, and 5.3m deep (not seen in this view). Internal: 2.4m high, 3.0m wide, and 4.0m deep. The door (not seen) is at the far end on the right side.

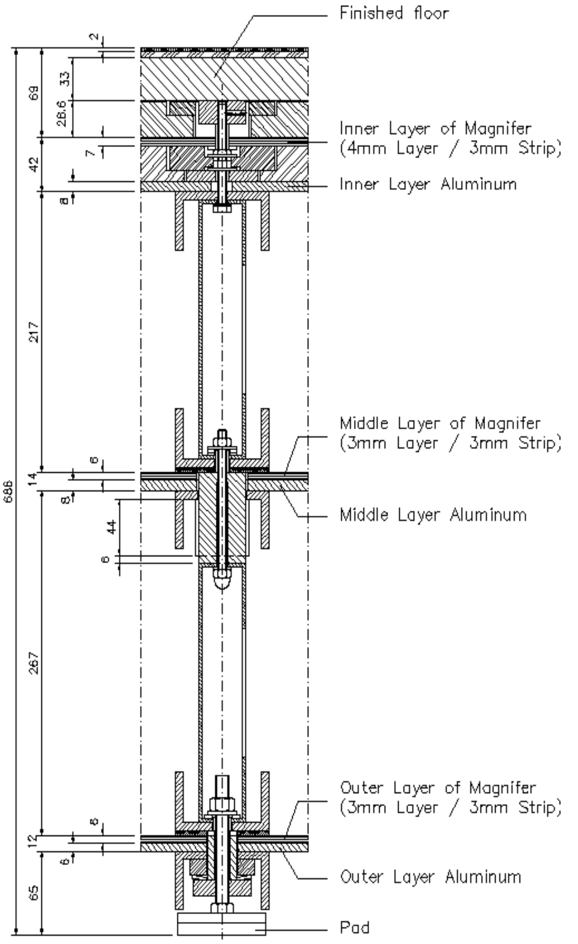

Figure 2. Section cut through entire floor of MSR. Other five sides are similar. Distances are given in mm. The larger structural members joining the three main layers are all of hard aluminum. The thick pieces of the inner layer are plywood.

each. Magnetic continuity is maintained by overlay strips. Some construction features are shown in Fig. 2. Insulating washers, not specifically labelled, are used in the screw assemblies, so that each main layer is electrically isolated to help eliminate rf, which could degrade SQUID performance. Electrical continuity of the aluminum is also maintained, by aluminum overlay strips, to allow ac eddy-current shielding, important at frequencies >1 Hz. After pre-assembly at the factory, it was decided to improve the conductivity of the alum. junctions wherever possible. To this end, at the MGH site, the junctions of the inner layer were electroplated with silver or gold, using a hand-plating kit, and only a de-oxydizing paste was used for the outer two layers. The overall appearance of the room is seen in Fig. 3.

The active system, designed for three dimensions, is mostly completed, but presently operating only in the vertical (z) direction. We here describe only the z-equipment; x and y are similar. A low-noise fluxgate magnetometer is mounted at the center of the roof and oriented perpendicular to it. This detector negatively feeds a dc amplifier through a low-pass network with very slow falloff, to minimize positive feedback and oscillation. The amplifier then feeds two square coils in series; each closely encircles the room , one around the ceiling edge, the other around the floor edge. However, this geometry in this MSR does not allow the negative feedback current to produce quite enough counter-field at the MEG inside the room. We solve this problem by passing the current through a positive loop around the fluxgate, making the feedback current "work harder".

Both shaking and degaussing wires are built into the MSR. The shaking wires can carry about 5 amps of 60-Hz current continuously, in order to increase the Magnifer permeability and thereby raise the SF; they toroidally link the four vertical sides of the outer main layer. The permanent degaussing wires are applied to all surfaces of the inner main layer. In addition, one heavy wire can be inserted through one wall and out the opposite wall, for occasional degaussing of all three layers simultaneously. This wire carries ~400 $amps_{rms}$ at 60 Hz, for a short time.

Figure 3. Photo of the MSR at the factory. The view is almost the same as in Fig. 1. The network of pipes surrounding the room support the six coils which produce the ac field for SF measurements.

4. Performance

We first discuss the passive SF. This was measured both at the factory, and after final installation. In both cases the external field was produced by a pair of coils for each of three directions, each pair crudely resembling a Helmholtz pair; at MGH it could also be produced by a remote rotating bar magnet. At the factory, the internal field was measured by a fluxgate-

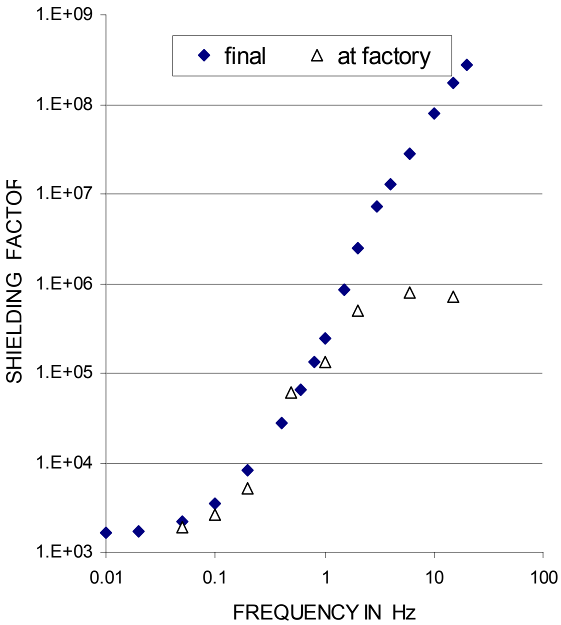

Figure 4. Measured passive shielding factor (SF) of the MSR, first after pre-assembly at the factory, then after final assembly at our site. The room was identical in each case, except for the improvement of aluminum junctions just before final assembly.

magnetomoter. At the final site it was measured first by high-Tc SQUID magnetometers, then later by the magnetometers of the MEG. Results are shown in Fig. 4. At 0.010 Hz the SF is 1,630 (64dB), better than the 58 dB design value. At frequencies >20 Hz, the field became non-uniform in the room, and these values were not plotted. The difference in SFs between the factory and final assemblies show the effect of plating the inner aluminum junctions, and using the paste on the outer two layers; however, the gain in SF would have been greater had we plated these outer layers as well.

The passive SF at 0.010 Hz is one way of comparing the various MSRs in existence. Thus, using fig.6 of [1], there are three better rooms: the new Berlin room (SF~80,000), the Cosmos "soccerball" room in Japan (~16,000), and the old Berlin room (~10,000). We are fourth (1,630), and we believe the fifth is the MSR at the Helsinki Univ. of Technology (~500).

Next, we discuss the active shielding. Our initial efforts easily improved the z-direction SF by a factor of 6-10 at 0.10 Hz. This was enough to make our total SF>78 dB, the original design goal. However, we encountered an unpleasant surprise: the low-frequency background at our site has recently increased considerably, compared with the older value of $20nT_{pp.}$ We now estimate ~100 nT_{pp} in the z-direction; this is seen in the MSR only by the MEG magnetometers, but disappears after 1am, hence is due to electric trains. Apparently the dc train wiring in downtown Boston was recently altered because of construction ("the big dig"), making new horizontal current loops. To compensate for this, and reduce the magnetometer interference to a modest level, we plan a 5-fold improvement in the active shielding. In any case, 4-D has supplied MEG software (signal-space projection) which, we have seen, reduces this type of background interference by the same factor of 5.

Concerning shaking, the SF gain was increased by a factor of 2, as expected [2]. But the 60-Hz signals seen in the MEG sensors, due to the shaking coil, was variable. When first tried, it was tolerable and could be filtered out. But several months later, it was much larger. This needs to be understood and corrected, so that shaking could be used when needed.

Although we are pleased with the passive SF and can cope with the problems mentioned above, there is one problem which is more difficult to solve. The inner magnetic layer, when mechanically perturbed, gives rise to large signals in the magnetometers, for example, when walking inside the MSR; we note that the floor is not independently suspended. This problem is caused by the four Magnifer sheets making up this layer, which can move and "rub against each other". We recently reduced the signals by pop-riveting the sheets together, on all six sides, and will eventually take other measures. However, the problem does not hamper any actual MEG data measurements to date, and may show up only in very special cases, perhaps involving dc measurements.

5. Acknowledgements

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6. Literature

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