The 8-layered magnetically shielded room of the PTB: Design and construction

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1 Introduction

The Physikalisch Technische Bundesanstalt (PTB) is extending its working facilities in Berlin. As part of the extension a new magnetically shielded room having an extraordinary performance was planned. The first efforts to define the specification were already undertaken in the late 80ies by Prof. H.-D. Hahlbohm and his co-workers. In 1989 VACUUMSCHMELZE made a first study on the design of a shielded room to meet these demands. In December 1996 SIEMENS AG in collaboration with VACUUMSCHMELZE GmbH & Co. KG received the order to design and construct this shielded room.

2 Design of the shielding system

2.1 Required shielding factors

The design goal is to create a measuring space with a residual magnetic noise in the range of several fT/√Hz in the magnetically hostile and vibration affected environment of a big city. Magnetic noise measurements at the site showed a typical level of several nT/√Hz in the frequency range 0.1 to 1 Hz and at power frequencies (see Fig. 1). Thus a shielding factor S, defined as the ratio of outer field to inner field amplitude, of 10^6 has to be achieved for the frequency range 0.01 to at least 500 Hz.
In the last two decades several multilayer magnetically shielded rooms were built [1,2,..5]. The maximum shielding factor achieved at 0.01 Hz is about 10^4. To compass $S = 10^6$ at the low frequency end an additional active shielding was incorporated for this site.
The demanded minimum passive shielding factor for the lower frequencies is shown in Fig. 2.

2.2 Design of the magnetic shield

Starting with the knowledge gathered by constructing the BMSR in 1980 [1] and with the experience of the development of the standard shielding rooms [6] we designed a room comprising 7 magnetic layers of MUMETALL with varying thickness and one highly conductive eddy current layer consisting of 10 mm Aluminum.

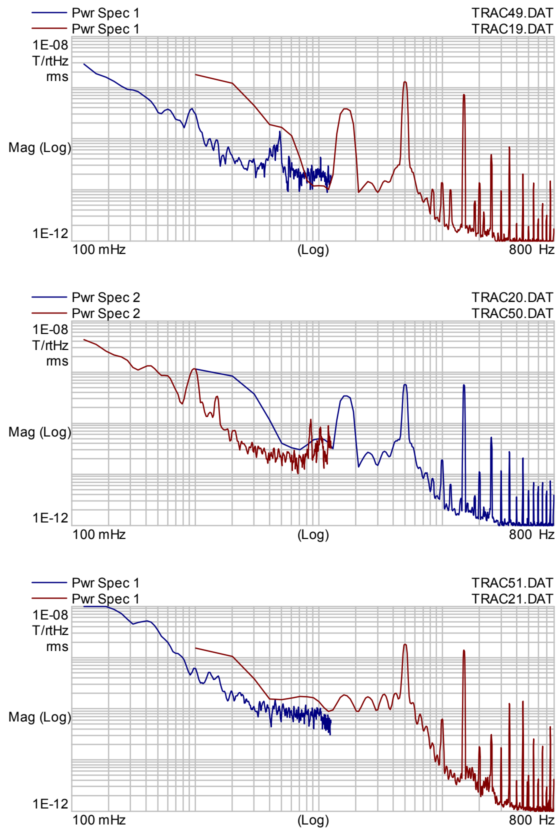

Figure 1: *The components of the daytime magnetic noise x, y, z (vertical) from top to bottom measured in the center of the empty building. For each component two spectra were recorded to have enough resolution over the whole frequency range.*

The needed working space is a cube with 2.9 m edge length. The mechanical constraints imposed by the supporting structure (see 3.2), leads to a set of edge lengths for the magnetic and the eddy current shells (see Table 1). From the standpoint of optimal shielding efficiency the innermost magnetic shield should be the thickest. Because metallic sheets produce thermomagnetic noise, it was decided to limit the thickness of the inner shell to 4 mm.
With these restrictions only the thickness of the outer MUMETALL shells were optimized with the program described in [6]. Rounding the results to multiples of 1 mm led to the thickness' given in Table 1.

Table 1: *Dimensions of the shielding shells of the magnetic shield*

No	Inner dimension /mm	Thickn. / mm	Material
1	3200	4	MUMETALL
2	3540	7	MUMETALL
3	3880	6	MUMETALL
4	4220	3	MUMETALL
5	4580	10	Aluminum
6	4930	3	MUMETALL
7	5270	2	MUMETALL
8	5610	2	MUMETALL

With these parameters and an assumed minimum wall permeability for the MUMETALL shells μ_{wall}= 13000 the shielding factor for the frequencies 0.01 to 100 Hz was calculated (see Fig. 2). At 0.01 Hz with 24,3 t net weight of MUMETALL a passive minimal shielding factor 24000 is calculated.

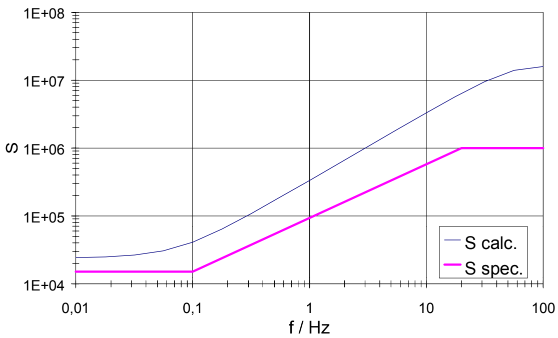

Figure 2: *Low frequency passive shielding factor, S_{spec}: minimum specification, S_{calc}: calculated with μ_{wall}=13000 and parameters from Table 1 .*

2.3 Design of the coils for Earth field compensation and active shielding

The factor lacking up to 10^6 has to be gained by an active shielding. The side length of the square coil system to compensate for the magnetic field was set to 11.9 m to provide sufficient space with acceptable field homogeneity. For each of the 3 axis of the building 4 square coils with 1 turn each with an 50mm^2 and a 1.5mm^2 Copper cable were installed.
The coils with the high Copper cross section are used to compensate for the stable part of the Earth magnetic field. The four coils of each of the three axis are at a time connected to a highly stable adjustable DC- power supply. The coils with the thin cable are used for the active shielding.
The spacing for the four coils was optimized for homogeneity under the constraint of a minimal spacing necessary for the z axis. None of the horizontal coils had to interfere with the entrance hall way which needed to be at level with the floor of the central working space.
For the active shielding three fluxgate sensors are fixed on the outside of the magnetic shield one each on the center of the left side the rear side and on top directed with its axis vertical to its surface. The digital controller is programmable and was developed by IDE[1] in collaboration with VACUUMSCHMELZE.

3 The structure of the shielding system

3.1 The building , foundation, RF shield and compensation coils

For the shielding system a separate building with 15 m cubic outer dimension and an two story annex with rooms for data acquisition and patient preparation was erected (see Fig. 3).

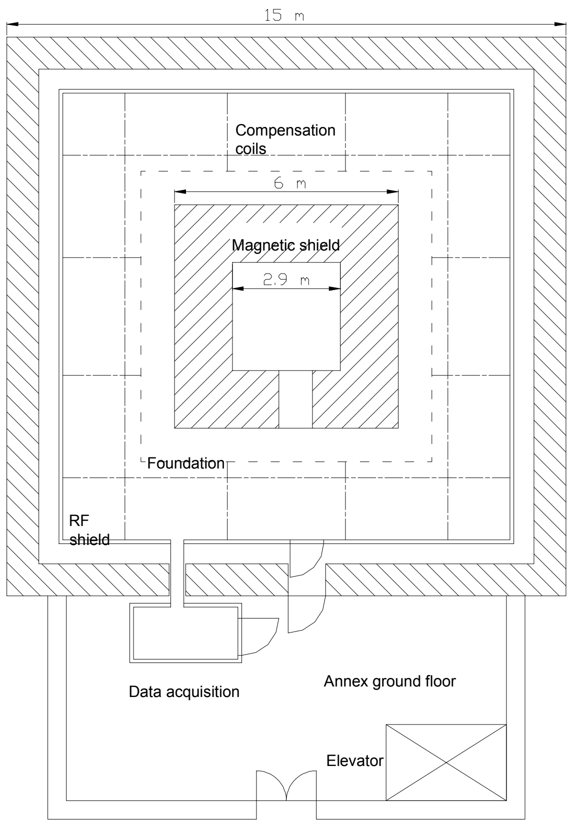

Figure 3: *Horizontal cut view through building, shielded room and annex with data acquisition chamber .*

The upper floor of the annex is at level with the inside floor of the magnetic shield. The main building houses a cubic RF shield with 12 m edge

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length. It protects the measurement equipment from interference by radio and mobile telecommunication transmitters and encases the whole setup including the compensation coils. For the data acquisition equipment a separate shielded room is provided. It is located at the lower floor in the annex and is connected to the big shield via RF-tight corrugated metal tubes.
To prevent from interference by vibrations a massive concrete foundation underneath the central 6 m shielding cube is built.

The cables of the compensation coils are fixed in guiding rails that are fastened with short spacers to the close RF shield surface. In the foundation residing on the bottom layer of the RF shield small tunnels for the installation of the coils were designed.

3.2 The magnetic shield

Besides the demands for the shielding factor the mechanical stability of the support structure for the shells of shielding material had to comply with the needs concerning the vibration amplitudes for the walls and the fixation points of the SQUID gantry. We decided to build this structure with sandwich panels.
These consist of an outer frame of hollow rectangular profiles, the inside honey comb from Polypropylene, and the cover sheets, which are glued on both sides. The profiles and the cover sheets are made from glass fiber reinforced resin. For the production it was reasonable to manufacture all panels in the same thickness. The value 150 mm was chosen.
To attain a solid inside floor, a rigid fixation for the gantry and a support for the ceiling of the inner magnetic shell, we had to take the sandwich as the innermost layer. For protection reasons and for the planned sliding door mechanism also a solid outer shell is needed. Thus a total of 9 sandwich layers support the 8 shielding shells. The sandwich layers are kept at 20 mm distance by spacers to provide the space for mounting the MUMETALL shells. For the eddy current shell 35 mm distance is needed.
The magnetic shells consist of plane and edge elements built up with strips of 0.5 mm finally annealed MUMETALL like for the standard shielded rooms made by VACUUMSCHMELZE.
The construction of the magnetic shell started on the foundation with the outmost floor sandwiches and proceeded with the next shielding and sandwich layer in alternation up to the innermost sandwich. Then the inner cube was completed and on its surface the MUMETALL shell mounted. Fig 4 shows a basic drawing of the setup and Fig. 5 shows a photo of the situation after mounting the first magnetic shell.

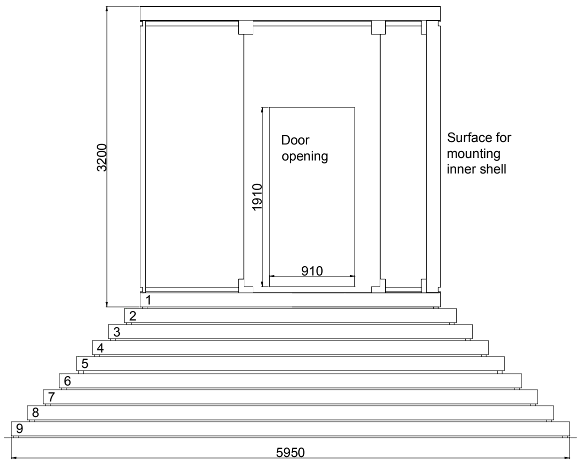

Figure 4: *Drawing of the floor sandwiches and the inner Sandwich cube view of the door side.*

Figure 5: *Photograph of the magnetic shield under construction, view on the top, the right wall and the rear wall of the inner cube with the first MUMETALL shell.*

For each of the magnetic shells a set of 4 coils is installed for demagnetization (idealization). The connections for the coils of the 4 inner shells are lead to a terminal box inside the shield and the ones for the 3 outer shells are lead to a box on the outside. The demagnetization is performed with a motor driven variable transformer.

For each two shielding shells a pneumatically driven sliding door is installed. The door blades covered with the shielding material can be pushed against the shells for closing, or can be contracted reducing the thickness of the door. To open the door it is pushed in a cavity between two shells formed by prepared cutouts in every second sandwich layer on the left side of the door opening.

4 First results

In the mid of June 2000 the shielding system (with the preliminary short name MSR L1) was completed and first measurements were taken. We determined the shielding factor S defined as $S = H_o/H_i$. The outside field H_o is produced by a set of square coils mounted on the outside surface of the building, two for each of the 3 axis. The inside field H_i is measured with a low noise SQUID-vector-magnetometer, designed and manufactured by the PTB. The shielding factor measured with $H_o \leq 1\mu T_{rms}$ averaged over the three directions, different positions within the working volume and the center of the room is given in Fig. 6 together with shielding factors published for other rooms. Above 5 Hz the shielding factor of the new chamber is more than $2\ 10^8$ which is the present limitation of the used detector system.

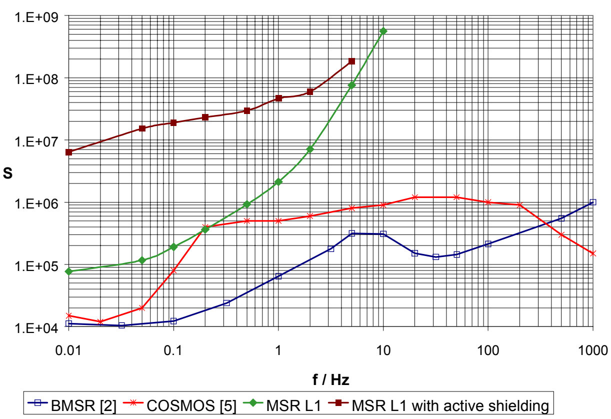

Figure 6: *Shielding factor over frequency for MSR L1 and other shielded rooms.*

5 Conclusion

The completed facility delivers a passive shielding factor at 0.01 Hz of 75000 and with active shielding over $2\ 10^6$ are achieved. The results show that this shielding sets a new world record for passive and active shielding performance.

Acknowledgements

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