Large Spherical Magnetic Shield Room


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A unique large magnetic shield room of the spherical type has been constructed on the new campus of the Institute of Space and Astronautical Science. A spherical shield room is theoretically of good design to produce a nice uniform field inside it. The purpose of the magnetic shield room is to test the magnetic characteristics of spacecraft, satellite, sounding rocket payload and their subsystems, the calibration of magnetometer and others. The present shield room is also used as an electric shield room. Therefore, it is quite useful to check the electro-magnetic interference of payload system and to calibrate the high sensitive electronic circuit. The present paper describes the design and the shielding characteristic of the room. The authors wish that the shielding room can be used effectively by many investigators in the space science field and others. It is the authors desire that the shielding room will be utilized effectively by numerous investigations, not only in the space science field but also that of other fields of research.

1. Introduction

The earth's magnetic field is always disturbed temporarily as well as spatially by such human activities as electric railways and industry. The disturbance is induced directly by the motion of magnetized material or indirectly by the electric current flowing through the ground. The temporal disturbance is quite random and reaches easily up to a few hundred nT in city areas. Among them, the effects caused by electric railways are quite large and almost diminishes only during 1.30 AM and 4.00 AM. Spatial disturbance reaches a few hundred nT per meter easily in buildings. Therefore, it is almost impossible to compensate for these disturbances by means of the combination of magnet and electric coil.

To avoid these disturbances and develop a free configuration of the magnetic field, a magnetic shield room is important.

The Institute of Space and Astronautical Science conducts projects of scientific satellite and space probe. A satellite in near-earth orbit is affected in its altitude by the earth's magnetic field if it is magnetized. The satellite or space probe which measures the magnetic field must be as magnetically clean as possible. Therefore, it is necessary to measure the magnetic property of the spacecraft
or sometimes its subsystems.

The Institute constructed a large magnetic shield room in the Environmental Test Building of its new, Sagamihara campus, Sagamihara city, Kanagawa-Prefecture, to achieve the above-described process.

2. Design Principle

There are several large magnetic shield rooms (MAGER, 1976). They are of the usual square room type covered with high-$\mu$ metal plate. In this case, however, the magnetic line of force in the high-$\mu$ metal does not connect continuously at the corner edge and resultantly a free magnetic charge appears. It decreases the effective magnetic shielding of the shield room. To reduce this negative effect of the corner, some curved plates should be attached over these corners.

On the other hand, the spherical shell type high-$\mu$ metal room has theoretically no such difficulty and the effective permeability of high-$\mu$ metal approaches the ideal case. The interior magnetic field is also expected to be more uniform than other types such as the square room. However, the actual construction of such a spherical shell of large dimension has more technological difficulties, particularly in the construction of the door.

The present magnetic shield room is a spherical type with three layers of high-$\mu$ metal. The diameters of the outer, intermediate and inner shells are 8 m, 6.8 m and 6 m, respectively. Outer and inner shells of high-$\mu$ metal are fixed on the surface of independent aluminum spherical shells and the intermediate high-$\mu$ metal shell is supported by the inner aluminum shell. The biggest problem is how to connect magnetically the doors, the large one is 2.5 m $\times$ 2.5 m for instruments and the small one, the entrance for human, is of 0.8 m $\times$ 1.3 m, to each shell. Actually, the doors are double, not triple, like shells, so that outer door is attached to the outer shell and inner one to the inner shell. All doors are pressed to the shells mechanically as tightly as possible to make the magnetic connection between door and shell better.

The three layers are electrically insulated from each other and the ground, and the total system is also supported by ceramic. Being so designed, this magnetic room can also be used as an electric shield room even from the commercial power line induction of 50 Hz.

The shielding of the magnetic field by one spherical shell is expressed as follows.

\[
\frac{H_o}{H} = 1 + 2 \frac{t \mu}{3r}
\]

where $H_o$ and $H$ are magnetic fields of outer and inner space of the spherical shell, respectively. $\mu$ is the specific permeability of the material of shell, $t$ is thickness of shell and $r$ is the radius of spherical shell as shown in Fig. 1. Therefore, shielding effect increases when the thickness of the shell is large and the radius of the shell is small.
When several shells are used, the shielding capability increases. As an example, the shielding effect can be expressed as follows when three layers are used.

\[ \frac{H_o}{H} = 1 + S_1 + S_2 + S_3 + S_1S_2V_{12} + S_2S_3V_{23} + S_3S_1V_{31}, \]

where

\[ S_i = \frac{2/3 \frac{H_i}{r_i}}{r_i} \quad \text{and} \quad V_0 = 1 - \left( \frac{r_i}{r_f} \right)^3. \]

From this equation, we can estimate the optimum design parameter when the radii of the outer and inner shells are fixed.

In the present case, the inner diameter was decided on as 6 m in order to keep enough space to make the magnetic measurements of the whole spacecraft which will be launched by the Mu rocket or that of the whole payload of the sounding rocket. The diameter of the outer shell was determined as 8 m after taking into consideration the size of available room in the Environmental Test Building of ISAS at Sagamihara City. Then the diameter of the intermediate spherical shell for optimum shielding was calculated at about 6.8 m by the last equation.

Some numerical examples are shown in Fig. 2 with the abscissa of shielding rate and coordinate of effective permeability of the shielding material (Super permalloy). The uppermost curve shows the shielding characteristics of the present shield room.

From the results obtained by other large shield rooms ever built, the effective permeability is expected to be at least 30,000. Therefore, a shielding rate of 1,000 is expected.

3. Structure

As previously described, the magnetic shield room is designed basically as three layered. However, it was quite difficult to make the openings, one for
the transportation of the spacecraft, which is 2.5 m wide \times 2.5 m high and another for the experimenters entrance, which is 0.80 m wide \times 1.3 m high, three layered. Therefore, the doors for these openings are two layered.

For the outer and inner shells, two aluminum spheres were constructed. The outer shield wall, curved superpermalloy plates of 2 sheets of 1.5 mm thickness were attached to the outer surface of the outer aluminum sphere and a similar inner wall to the inner surface of the inner sphere. The intermediate shield wall which also consists of a double sheet is supported by the electrically insulated materials on the outer surface of the inner aluminum sphere.

The doors for instruments and that for human entrance are both twofold, as described previously, and constructed of aluminum covered also by double sheet permalloy plate. These doors are strongly compressed to the outer and
inner spherical shells by lever handle to minimize the magnetic resistance between door and shell. The door contact has also electric contact of Cu-Be spring. As mentioned before, the shield room has two aluminum spherical shells. Therefore, it acts also as an electric shield room, provided the doors have good electric contact with the aluminum sphere.

Inside the inner wall, three coil systems are installed. These axes of coils are perpendicular with each other and are simulated to the Helmholtz type as close as possible. These coils are used to eliminate the magnetic field in the shield room as well as to establish certain magnetic fields up to the equivalent field of the earth's magnetic field. To do this the electric currents are fed from the control rack. However, to eliminate the electric disturbance which intrudes into the shield room along these current lines, these lines can be disconnected at the terminal box which is attached to the outershell of the shield room.

It is important to make degaussing of shells to reduce the magnetic field inside the shield room, especially when the instrument door is once opened and closed. The degaussing is made by alternate current which flows along the one-turn coil as shown in Fig. 3. An example of the degaussing operation effect is shown in Fig. 4.

4. Capability/Performance

4.1 Static magnetic shielding effect

An example of mapping inside the shield room at the height of 120 cm from the floor is shown in Fig. 5. Roughly speaking, the magnetic field at the center position of the shield room is almost 10–15 nT resulting that the shielding ratio is more or less three thousand. It means that the effective permeability of the total material is about 40,000 and more than 1.3 times larger than expected as presumed from Fig. 2. This result shows that the construction method such as magnetic contact has been made quite successfully, probably due to the

![Fig. 3. Schematic diagram of degaussing system. Degaussing is made with single turn coil mounted along an half spherical shell in one meridian.](image-url)
Fig. 4. Effects of degaussing. Measurement of degaussing effect by a magnetometer inside the shield room. Degaussing is made by two steps, one is by decreasing current from 600 A to 0 and second one is from 10 A to 0.
spherical geometry of configuration.

As far as the magnetic field distribution is concerned, some anomaly has been found in one corner of the shield room. The anomaly seems to be caused by anomalous magnetization of some part of the shielding wall. This anomalous magnetization will be checked afterwards and will be reduced as much as possible. Nevertheless, the magnetic field inside the shield room is quite small and the uniformity of the field is fairly good at the center of the shield room.

4.2 Stability of magnetic field inside the shield room

One of the important roles of the magnetic shield room is to diminish the magnetic disturbance due to electric current flowing in the ground or moving magnetized material like cars, because these disturbance sources are always accompanied with human activity. Two sets of magnetometer, normal high sensitivity magnetogram and induction magnetogram were set in the shield room. Their sensitivities are 0.1 volt/nT and 1.7 V/nT at 9 sec, respectively. From continuous recordings taken throughout a night, the noise level was found to be less than 0.2 nT peak to peak or 0.013 nT at 9 sec.

However, the inside field changes when the instrument door is once open and closed. The change is clearly reduced to the order of 0.1 nT after degaussing of the shield wall is made. This may be caused by the change of contact conditions between the door and spherical wall.

4.3 Electric shielding

In the design of the shield room, the electric shielding effect is expected to be more than 80 db for VLF frequency range. As the VLF range is quite
an important range in space science observations, the above requirement is rather serious from the view point of scientist. The result of the measurement by means of transmitter, receiver and loop antenna shows the shielding effect in the frequency range from 10 KHz to 30 MHz is always larger than the maximum measurable value like 83 decibels.

Therefore, it is concluded that the actual shielding is more than designed one.

One important capability is a shielding of commercial power line radiation. In the present case, comparison has been made between inside and just outside of the shield room by using a very low noise tuning receiver and loop antenna which is 8000 turned with a core of 50 cm long and 6 mm x 6 mm cross-section and electrostatic shielding. All cables through the shielding wall were cut at the surface of the outer shell. Under these conditions the difference between outer and inner magnetic field of commercial power line is -80 db or more. Thus, this shield room can be used even in the frequency range of ELF.

5. Conclusion

A large spherical magnetic shield room has been constructed in the Environmental Test Building on the Sagamihara Campus of the Institute of Space and Astronautical Science. Such a spherical shielding room is theoretically good geometrical configuration for shielding but its actual construction is rather complicated.

The shield room actually built shows a better performance than expected. It shows also a good performance in the shielding of the electric field. It has been used for electro-magnetic interference checks of the space probes for spacecraft and sounding rocket. The interplanetary magnetic field experiment onboard the MS-T5 spacecraft has been tested successfully to check for interference from the spacecraft itself.

There remains still some ambiguous problems which have to be clarified.

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REFERENCE