Simple Design Method for Magnetic Shield Room

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As a primary evaluation of the magnetic shield room design, a simple design method is proposed here. The steel sheet number of the magnetic shield room is designed so as to make the distributed magnetic flux density from the exciting coil catch the magnetic shield body. The proposed method is applied to a full-scale magnetic shield room and the leakage magnetic flux density is evaluated by numerical calculation. Though it introduces a large steel number of the magnetic shield body, the leakage magnetic flux density of the designed magnetic shield room decreases extremely in all area of the magnetic shield room.

Keywords: magnetic shield room, shield design, equivalent BH method, numerical calculation, leakage magnetic flux density, silicon steel.

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1. Introduction

Magnetic shield room is expected to be an important technology to protect the health of patient such as using a pacemaker. An electrical apparatus with super conductive magnet and many electric devices, which are shut in a small space especially on a big city usage, make people being applied to by high magnetic field [1-3]. In particular, the demand for higher magnetic field rises in the MRI device, because the vividness of a measured image is in proportion to the magnetic field [4-6]. Then the magnetic shielding room design is important for the realization of higher magnetic field in a small space.

To obtain the patient mental relaxation and the superior magnetic shielding performance, a new type of magnetic shield room called “open type” is proposed [7, 8]. It has a transparent characteristic to release the patient mentality and a blind type structure in consideration of magnetic anisotropy of the material.

To design it, only the experimental technique is not enough because of taking a lot of time and money. Then the combination with the numerical analysis technology is preferable to obtain the parametric study and to evaluate the designed shielding room.

The open type magnetic shielding room contains a lot of thin steel sheets, which is used for shielding the supplied magnetic field. Then the problem of mesh explosion occurs, because fine mesh division, which is necessary for thin steel sheets, has to apply to the large scale magnetic shield room.

With this purpose, an equivalent B-H method is newly devised [9, 10]. When this method is applied to an on-line used magnetic shielding room, it is able to express the leakage magnetic field precisely.

However, it takes a lot of time to calculate in one case such as around several hours or so. Then, a further simple tool to handle easily and to realize a small calculation time, less than a few seconds, is necessary to obtain the efficient design circumstance of the magnetic shielding room.

Therefore, a simple design method is proposed here as a primary evaluation of the magnetic shield room design, where it is assumed that the magnetic field from the electric apparatus is given in beforehand. Then, the details are shown as follows.

2. Simple Design Method

2.1 Open Type Magnetic Shield room

Fig. 1 (a) shows a bird’s-eye view of the open type magnetic shielding room. There is an exciting coil (DC) inside the magnetic shield room, which is supposed to be an MRI coil.

The shielding room consists of an inner shield body and an outer shield body. The construction of the outer shield body is shown in Fig. 1 (b). Thin steel plates are arranged in parallel crosses in the X–Y plane and are piled up in the Z-direction in bamboo blind pitch. The thin steel plates of the inner shield body are also arranged in parallel crosses in the Y–Z plane and are piled up in the X-direction in bamboo blind pitch. The inner shield body is arranged just inside the outer shield body.

Here, Grain-oriented steel (GO material) is used as thin steel plates [11–13]. The GO material has high magnetic permeability and high saturated magnetic flux density, which are necessary for the magnetic shielding material. Since the GO material has strong magnetic anisotropic characteristic as well as non-linear characteristic of magnetic saturation, the anisotropic and non-linear characteristics should be considered when the magnetic shielding room is calculated.

The opening type has a superior characteristic to let shield materials catch the generated magnetic field. However, when local magnetic saturation is generated

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in a part of the magnetic shield room, the leakage magnetic fields there increase because magnetic flux density is hard to go to the neighbor shield materials [8]. Therefore, it is a particularly important thing for the open type magnetic shield room to be designed adequately for a generated magnetic field.

2.2 Simple Design Method

A simple design method is proposed here as a primary evaluation of the magnetic shield room design.

It is assumed that the magnetic field to be shielded, which is generated by an exciting coil, is given beforehand. The design is performed so as to make the magnetism shield body catch the magnetic field. Because the total amount of magnetic flux is constant, the more magnetic flux the magnetic shield body catches, the smaller the leakage magnetic field is. Because magnetic flux is closed and continues, the leakage magnetic field should diminish theoretically when the magnetic field at the magnetic shield room position is absorbed into the magnetic shield body completely.

Since the magnetic flux is distributed, the number of the magnetic shield steel sheet should also be distributed.

Now the case that there is an excitation coil inside the magnetic shield room is considered as shown in Fig. 1. It is considered that the magnetic shield room consists of a rectangular solid with 6 planes, which are 4 side planes of plane-A, B, C, D and ceiling and floor. For an example to design a magnetic shield room, a rectangular plane-B, in which one side is \( l_1 \) and \( l_2 \), is considered here.

It is supposed that the magnetic flux density in an arbitrary point \( \vec{x} \) in plane-B is \( \vec{B}(\vec{x}) \). Then the magnetic flux \( \Phi_B \) in the plane-B is given by the next equation.

\[
\Phi_B = \sum_{x \in \text{plane-B}} || \vec{B}(\vec{x}) || \Delta S_x
\]

Here, \( \Delta S_x \) is a small area at point \( \vec{x} \).

If magnetic flux \( \Phi_B \) is caught by a magnetic shield body in plane-B all, it is considered that a leakage magnetic field does not exist outside plane-B.

Now, it is supposed that the representative length in plane-B is \( l \), and the thickness of the steel sheet of the magnetic shield body is \( d \), and the average magnetic flux density that should be caught by the magnetic shield body is \( \vec{B} \). Then it is said that \( dl \vec{B} \) is a magnetic flux that should be caught by the magnetic shield body.

If \( dl \vec{B} \)accords with the magnetic flux \( \Phi_B \) in plane-B, the magnetic flux will be caught by a magnetic shield body. Therefore, the thickness \( d \) of the steel sheet of the magnetic shield body is expressed by the next equation.

\[
d = \frac{\Phi_B}{l \vec{B}}
\]

As for the representative length \( l \) in plane-B, some ideas are considered such as the maximum of the side of plane-B. Since the representative length \( l \) is conceptual such as a length of Reynolds number in fluid dynamics, it is not fixed uniquely. However, since it is necessary to fix a certain value to evaluate this method, the next equation is used here. It is easy to calculate.

\[
l = \sqrt{l_1^2 + l_2^2}
\]

As for the average magnetic flux density that should be caught by the magnetic shield body \( \vec{B} \), it is assumed \( \vec{B} = 1T \), which is near the point where the magnetic permeability becomes maximum.

The thickness of the steel sheet of the magnetic shield body \( d \), which is derived in Eq. (2), corresponds to the thickness of the steel sheet in conventional closed type magnetic shield room. In open type as shown in Fig. 1 (b), it is considered that the thickness of the steel sheet is \( d_s \), the width is \( W \), and the bamboo blind pitch is \( p \). Then the next equation is provided, because the quantity of steel materials of the unit length agrees with the open
type and the closed type.

\[ dW = dp \]  

From this, the thickness of the steel sheet \( d_i \), which is a demanded value, is introduced. The steel sheet number in plane-B is introduced by being divided by the thickness of steel sheet (0.35 mm thickness is used here) with the thickness \( d_i \).

Here, since it is assumed that the magnetic flux density on plane-B is distributed uniformly, the number of the steel sheet on plane-B becomes all the same. The procedure to decide the steel number in plane-B of Fig. 2 is also applicable to the one in the other planes likewise.

### 2.3 Design Results

The proposed simple design method is applied to a full-scale magnetic shield room of length 5.5 m, width 3.3 m, height 3.3 m [9]. The exciting coil is arranged at 200 mm apart from plane-B. The construction structure of the magnetic shield room, which is considered in [9, 10], is ignored here for the convenience.

Table 1 shows the steel numbers of the magnetic shield room introduced by the conventional method [9] and the ones by the proposed simple design method.

The conventional method has allotted the steel sheet number 20 to evenness, without depending on the distribution of magnetic flux density of the exciting coil.

The simple design method calculates the steel sheet number of sheets, which is different for each plane. The magnetic flux from the exciting coil is distributed. It increases at the near plane to the exciting coil, but it decreases at the far-off plane.

Especially, the steel sheet number of the floor increases extremely, since the floor is next to the exciting coil, and then the total steel sheet weight increases.

### 3. Applied to Magnetic Shield Room

To evaluate the shielding performance of the magnetic shield room designed by the proposed simple design method, leakage magnetic field distribution is calculated by numerical analysis based on equivalent B-H method. The conventional method is also calculated for comparison.

Fig. 3 is magnetic characteristics of GO material used here. It has superior magnetic characteristics in easy magnetization axis, in which the main magnetic flux flows in the magnetic shield room.

Fig. 4 shows the calculated leakage magnetic flux distribution along Z-direction at center position of the exciting coil.

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Table 1 Steel sheet number of designed magnetic shield room.

<table>
<thead>
<tr>
<th></th>
<th>Conventional method</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane-A</td>
<td>20</td>
<td>47</td>
</tr>
<tr>
<td>Plane-B</td>
<td>20×2-plane</td>
<td>4×2-plane</td>
</tr>
<tr>
<td>Plane-C</td>
<td>20</td>
<td>47</td>
</tr>
<tr>
<td>Plane-D</td>
<td>20×2-plane</td>
<td>38×2-plane</td>
</tr>
<tr>
<td>Floor</td>
<td>20</td>
<td>103</td>
</tr>
<tr>
<td>Ceiling</td>
<td>20</td>
<td>27</td>
</tr>
</tbody>
</table>

Total weight: 932kg, 2028kg

(p=300mm, W=50mm, Thickness of steel sheet: 0.35mm, density of steel: 7800kg/m³)
density. It is a leakage magnetic flux density distribution along Z-axis at center position of the exciting coil. Though the steel sheet weight increases 2.2 times, the leakage magnetic flux density falls to a one-fifth. It is said that the more shielding effect is obtained by using the simple design method than the increase of steel weight. The well-balanced design is important.

Fig. 5 shows a color contour expression of leakage magnetic flux density distribution. In the conventional method, a leakage magnetic field is mal-distributed. The large leakage magnetic flux density at plane-D, A, C and floor, which are near to the exciting coil, is observed.

In the proposed method, a leakage magnetic field is distributed uniformly and in low level, including near plane-D, A, C and floor, which are near to the exciting coil. The design of the magnet shield body is performed adequately, since the proposed simple design method decide the steel sheet number so as to depend on the magnetic flux density distribution.

Fig. 6 shows the magnetic flux density distribution in the steel sheet of the magnetic shield body.

In the conventional method, some part of the steel sheet, which is near to the exciting coil, becomes large enough to reach the magnetic saturation area. The leakage magnetic flux density from that part becomes large.

In the proposed method, little part of the steel sheet reaches the magnetic saturation area, and then little leakage magnetic flux density is observed.

Therefore, it is said that the proposed simple design method designs the magnetic shield room well-balanced in consideration of the magnetic flux density distribution. It makes little steel sheet reach the magnetic saturation area, and then the leakage magnetic flux density becomes small.

About the calculation CPU-time, it takes about less than a few milliseconds for the proposed simple design method, though it takes more than a few days for the conventional method of Equivalent $B$-$H$ method.

Fig. 6. Contour expression of magnetic flux density at magnetic shield body (GO material). (a), (b) Inner shield body of conventional method and proposed method respectively. (c), (d) Outer shield body of conventional method and proposed method respectively.
4. Conclusion

As a primary evaluation of the magnetic shield room design, a simple design method is proposed here. The steel sheet number of the magnetic shield room is designed so as to make the distributed magnetic flux density from the exciting coil catch the magnetic shield body. The proposed method is applied to a full-scale magnetic shield room and the leakage magnetic flux density is evaluated by numerical calculation. Though it introduces a large steel number of the magnetic shield body, the designed magnetic shield room has little leakage magnetic flux density in all area of the magnetic shield room.

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References
