Neurology and Clinical Neurophysiology 2004:68 (November 30, 2004)

Active Magnetic Compensation Composed of Shielding Panels

Kato, K[1], Yamazaki, K[1], Sato, T[2], Haga, A[2], Okitsu, T[3], Muramatsu, K[3], Ueda, T[4],
Kobayashi, K[5], Yoshizawa, M[5]
[1]Takenaka Corp., Chiba, Japan, [2]Tohoku Gakuin Univ., Miyagi, Japan, [3]Saga Univ., Saga, Japan,
[4]KRI Inc., Kyoto, Japan, [5]Iwate Univ., Iwate, Japan.

Corresponding Author: Kazuo Kato, 1-5-1, Ohtsuka, Inzai, Chiba, 270-1395, Japan
Phone: +81-476-47-1700; Email: katou.kazuo@takenaka.co.jp

ABSTRACT

Magnetically shielded rooms (MSRs) with materials of high permeability and active shield systems have been used to shield magnetic noise for biomagnetic measurements up to now. However, these techniques have various disadvantages. Therefore, we have developed a new shielding system composed of shielding panels using an active compensation technique. In this study, we evaluated the shielding performance of several unit panels attached together. Numerical and experimental approaches indicated that the shielding factor of a cubic model composed of 24 panels was 17 for uniform fields, and 7 for disturbances due to car movement. Furthermore, the compensation space is larger than that of an ordinary active system using large coils rather than panels. Moreover, the new active compensation system has the important advantage that panels of any shape can be assembled for occasional use because the unit panels are small and light.

KEY WORDS

Active magnetic shield, Magnetic shielding panel, Sensor position, Shielding effect.

INTRODUCTION

Magnetic shielding systems, that is MSRs and active shielding systems, are widely used for biomagnetic measurements. An active magnetic shielding system, which is composed of coils, sensors, and controllers, is attractive compared with a passive MSR, from the standpoint of frequency dependence at low frequencies (under about 1 Hz), weight, and closed space. [Kato, 2000] [Brake, 1993] [Platzek, 1999] [Skakala, 1993]. However, ordinary active shielding systems using cubic-like large coils, several meters in size, and a sensor, have the disadvantages of a poor shielding effect for inhomogeneous or gradient magnetic noises generated by cars or elevators, a relatively small compensating area and the requirement to set up sensors where we want to cancel the fields. In order to overcome these disadvantages, a new active shielding system composed of shielding panels is proposed. In this system, the large coil of an ordinary system is subdivided into small panels, and each unit panel has a coil, a sensor and a controller. In this paper, the optimal design of the new system is implemented and the shielding performances are compared with those of ordinary methods, using numerical and experimental approaches.

SHIELDING PANEL SYSTEM

Figure 1 shows one panel of the new shielding system. Each of the square panels is about 500 × 500 mm, and is composed of a magnetic sensor (HMC1021S, Honeywell) for detecting the fluctuation of external magnetic noises positioned at

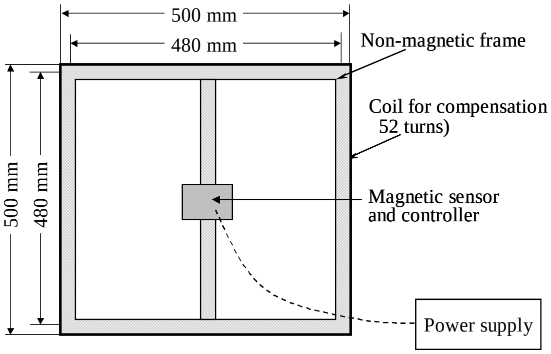


Figure 1. Magnetic shielding panel unit

the center of the panel, and a controller that generates compensation fields by sending current to the coil surrounding the frame, which is made of wood. The magnetic field signals acquired by the magnetic sensor are processed and used to determine coil currents so as to minimize the fluctuation of the magnetic field at the sensor position.

SIMULATIONS

Figure 2 shows a cubic model composed of 24 shielding panels used for numerical analysis. Parameters L_p, h, G_1, G_2, L_o in this figure correspond to the side length of the square coils, the sensor position distance from the panel surface, the gap between panels on the identical and differential planes, and the outer dimension of one side of the cubic model ($2L_p + G_1 + 2G_2$), respectively. In the numerical simulations, three models were considered: (A) a cubic model with gaps, (B) one without gaps, and (C) an ordinary model with non-divided large coils. The parameters for the models are given in Table 1. Uniform magnetic noise for the $-z$ direction at 0.7 μT and gradient noise increasing for $+y$ direction ($B_z = -0.3y - 0.7$) were applied. The magnetic fields were calculated by the Biot-Savart law. Thus, the fields $\boldsymbol{B(r)}$ at any position $\boldsymbol{r}$ when the magnetic field $\boldsymbol{B_0(r)}$ is applied and current $\boldsymbol{I_i}$ is fed to coil number i is determined by the following equation:

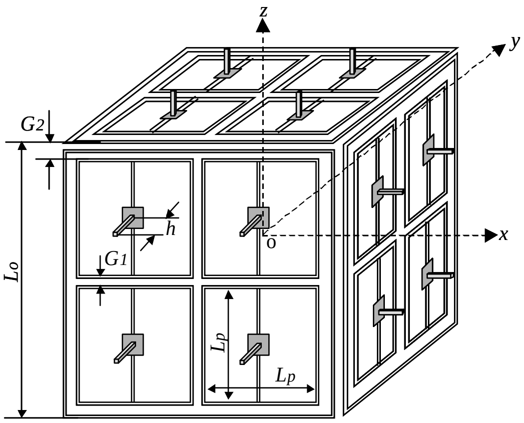


Figure 2. The cubic model composed of 24 shielding panels used in the numerical analysis and experiment

$$\boldsymbol{B}(\boldsymbol{r}) = \mu_0 \sum_{i=1}^{Nc} \sum_{j=1}^{Ns} \left(\frac{I_i \boldsymbol{ds}_j \times \boldsymbol{r}}{4\pi r^3} \right) + \boldsymbol{B_o}(\boldsymbol{r}) \qquad (1)$$

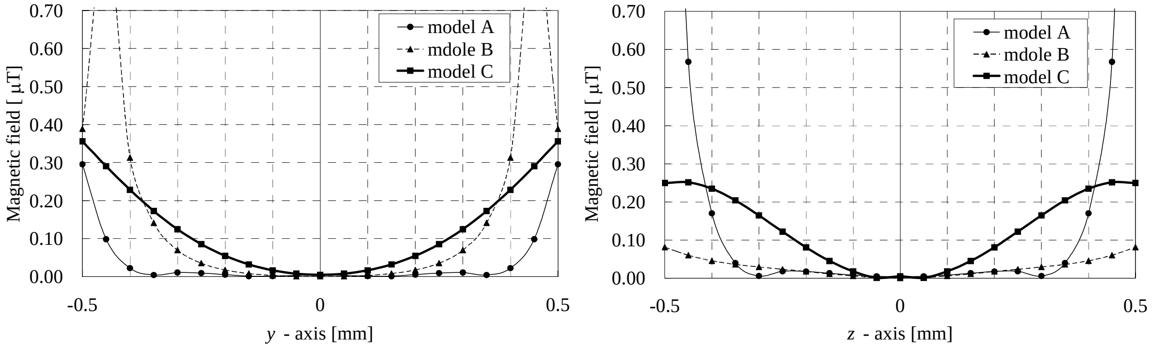
where N_c is the number of panels, N_s is the division number of coils, $\boldsymbol{ds_i}$ is a vector corresponding to a short section of the coil and μ_0 is the permeability of a vacuum. Current I_i is determined by requiring that the component of the magnetic field perpendicular to panel in Eq. (1) is zero at the sensor position.

model	Number of panels per surface	L_p	G_1	G_2	$\boldsymbol{L_o}$
A	4	480 mm	30 mm	55 mm	1,100 mm
B	4	500 mm	0 mm	0 mm	1,000 mm
C	1	1,000 mm	-	0 mm	1,000 mm

Table 1. Parameters of the three simulated models

The optimal sensor position of each model, which indicates maximum shielding performance, is 230 mm for Model A, 60 mm for Model B, and 250 mm for Model C, for both uniform and gradient fields. These results are described in detail in the section of experimental results on Fig. 4. Fig. 3 shows the changes of $|\boldsymbol{B}|$ along the y ($x = z = 0$) and z axes ($x = y = 0$) at the optimal sensor position for each model when uniform and gradient magnetic fields are applied. In Fig. 3(a)(i) for uniform and Fig. 3(b)(i) for gradient magnetic noises, Model A with gaps has a broader area of low magnetic fields than model B without gaps. Thus, it is assumed that the gapped model provides a better shielding effect for gradient fields. However, the shielding performances for gradient noises along the z axis fall away from the center point of the cubic model in Fig. 3(b)(ii). The shielding area of Model C is smaller, in general, than that for Model A or Model B.

(a) Uniform fields:



(b) Gradient fields:

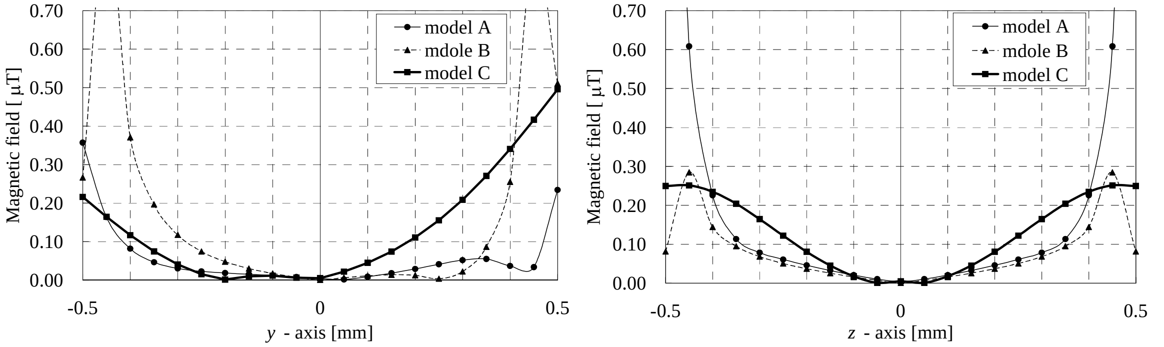


Figure 3. Magnetic flux distributions along *y* (left) and *z* (right) axes inside the shield of cube model in the case when *z*-directional uniform (a) or gradient (b) magnetic fields were applied.

EXPERIMENTS

For experimental measurements, the cubic model composed of 24 shielding panels (the same model as A in Fig. 2) was used. Shielding effects were measured for uniform sinusoidal-wave magnetic noises generated by 3-layered coils at 0.1 Hz applied on the -*z* direction at 0.7 µT [Sasada, 2003] and 3 direction gradient noises (B_x, B_y, B_z) generated by a moving car at a distance of 7 m from the model. Shielding effects were defined as the ratio of $|B|_{on}$ with active control to $|B|_{off}$ without active control evaluated by another magnetic sensor (Applied physics system, APS520A) at the cube’s center.

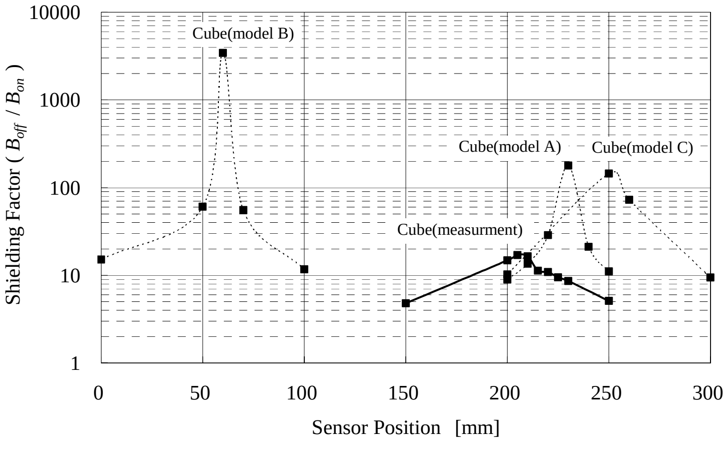
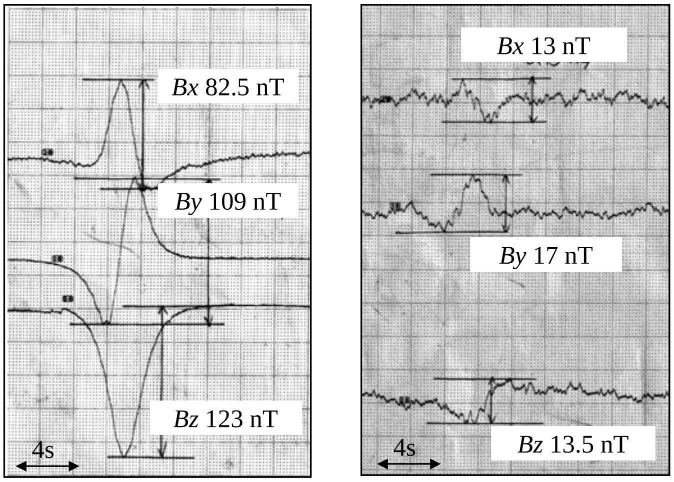


Figure 4. Shielding effects dependence on the sensor position from shielding panels

Figure 4 shows the shielding performance dependence on the sensor position together with the numerical results. The shielding factor of 17 was obtained by measurement when the sensor was set to the optimum position. It was also confirmed that the optimal sensor position of the experimental model was nearly coincident with that of the numerical analysis. Moreover, a shielding factor of 7 for the disturbance due to car movement was confirmed by the experiment shown in Fig.5.



(a) Without active control (b) With active control

Figure 5. Changes of magnetic field fluctuations without (a) and with (b) active compensation for car moving noises

DISCUSSION

The optimal shielding factor obtained from the experiment was worse compared with that obtained from the numerical simulation. This is because the position of sensor can not be set accurately at the optimal position in the experiment.

It is generally necessary to set the magnetic sensor detecting external magnetic noises on a place where shielding is required for an ordinary active shielding system. The system described in this paper can produce good shield effects and a broad compensation area with sensors placed at other points, that is, at the optimum position where the obtained magnetic fields are equal to that of the evaluating point. Moreover, it seems that the shielding method using panels is effective, and this system has the important advantage that panels can be assembled in any shape depending on various demands because the unit panels are lightweight and compact.

REFERENCES

Kato K, Yamazaki K, Matsuba H, Sumi C, Sato S. Active magnetic shield for biomagnetic measurements.. Proceedings of the 12th International Conference on Biomagnetism; Nenonen J, Ilmoniemi R, Katila T, editors. 2000 Aug 13-17, Espoo, Finland. Helsinki Univ. of Technology; p. 965-7.

Platzek D, Nowak H, Giessler F, Röther J, Eiselt M. Active shielding to reduce low frequency disturbances in direct current near biomagnetic measurements. Rev Sci Instrum 1999;70(5):2465-70.

Sasada I. Three-coil system for producing uniform magnetic fields. J Magnetics Society of Japan 2003; 27(4):612-5.

Skakala M, Zurbec V, Manka J. Active compensation for ambient magnetic noise in the unshielded environment. Meas Sci Technol 1993;4:468-72.

ter Brake HJM, Huonker R, Rogalla H. New results in active noise compensation for magnetically shielded rooms. Meas Sci Technol 1993;4:1370-5.