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Residual magnetization measurements of a motor to be used in satellites

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Abstract

A simple magnetic shielding system for residual magnetization measurements of a motor to be used in satellites is studied. The system consists of same-sized square coils, namely three sets of Simple Cubic-3 coil system. Because the system can generate a uniform magnetic field, we investigate the uniformity of the site. With a first-order gradient coil, the geomagnetic field can be reduced to less than 100 nT in a relatively large area. Inside of the system, the residual magnetization measurements of a step motor are demonstrated. An approach to reduce the magnetic field leakage from the step motor is also presented.

Keywords : Geomagnetic field canceling, step motor, magnetic moment, square coil system

1. Instructions:

Satellites are supposed to be able to control their positioning and stability in space. Therefore, the equipment installed in the satellite should be measured for residual magnetization during prelaunch[1]. In order to measure residual magnetization, the Japan aerospace exploration agency (JAXA), for example, has a ferromagnetic shield with triple spherical permalloy shells[2]. Although the shielding factor is as large as 60 dB for dc fields, typical magnetic fields inside a device are 20~40 nT. The usable area is limited because of the magnetization of the inner shell. Instead of a heavy ferromagnetic shielding system, the space research facilities are considering a geomagnetic field canceling system that uses the magnetic field generation coil[3]. A geomagnetic field canceling system requires uniform magnetic field generation over a considerable volume. From the point of view of practical advantages construction and usefulness, several kinds of square coil system have already been proposed. While the number of square coils allows the axial field to have good uniformity in a large volume, the size of the entrance area is limited by coil crossing for the three orthogonal coils sets. In order to drive one power supply in one direction, the ratio of the current in the coils should be an integer, and it is relatively tolerant of small design imperfections. For the reasons mentioned above, we have proposed a Simple Cubic-3 (SC3) coil system[4]. It consists of three square coils, with same coils' distance and a simple integer ampere-turn ratio.

This paper presents the results of residual magnetization measurements of a motor to be used in satellites with our proposed geomagnetic field canceling system. We chose a suitable site through the measurements of geomagnetic fields at several locations, and constructed a system with three sets of SC3. Combined with a gradient field generation coil system (G2), the geomagnetic field can be reduced to less than 100 nT in a relatively large area. Inside of the system, we demonstrate the residual magnetization measurements of a step motor. An approach to reduce residual magnetization is also presented.

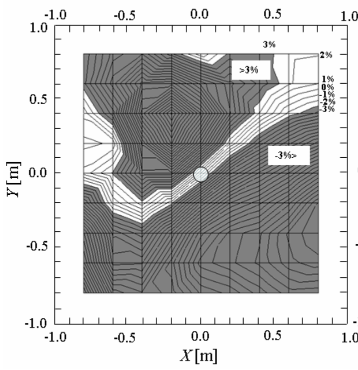
2. Geomagnetic field canceling system:

2.1 Geomagnetic field measurement

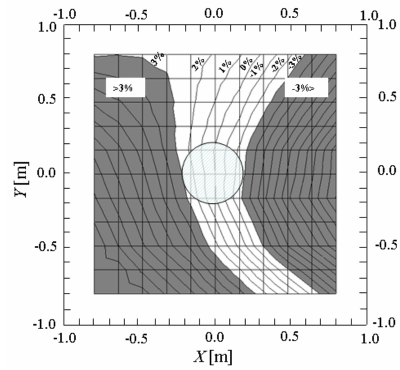
In order to choose a suitable site for the system, we investigated the uniformity of a magnetic field at four sites (Site 1: a typical laboratory room, Site 2: an electromagnetically shielded room, Site 3: an anechoic chamber with electromagnetic wave absorbers, Site 4: a wooden building room). We evaluated the uniformity of the geomagnetic field with deviation e as given by :

$$e = (|B| - |B_0|)/|B_0| \times 100\ [\%] \qquad (1)$$

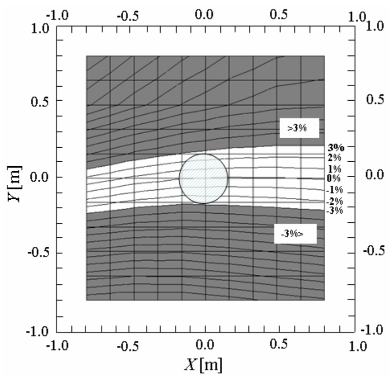
The center of the measuring area was determined to be the location where a value for the total magnetic flux density was measured. Measurement was done with a fluxgate sensor (FVM-400, MEDA). It is known that an SC3 coil system can provide a uniform magnetic field to within ±3% deviation inside a spherical volume of 0.5 diameter d, where d represents the side length of coil. From the measurements, the wooden building room (Site 4) was the best, because the area within the allowable ±3% deviation was largest. Fig. 1 shows the comparison of geomagnetic field distribution. The measuring plane is 1 m above the ground. The gray area represents the area beyond ±3 % deviation, and the circular area represents the area within ±3 % deviation. It was confirmed that an increase in the distance between the measuring point and the ground made the area within ±3 % deviation large.



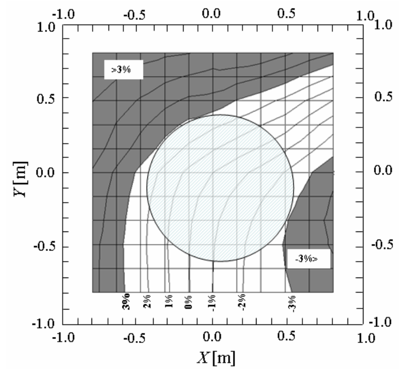
(a) Site1: typical laboratory room



(b) Site2: electromagnetically shielded room



(c) Site3: Anechoic chamber with electromagnetic wave absorbers



(d) Site 4: a wooden building room

Fig.1 Comparison of geomagnetic fields. The measuring plane is 1 m above the ground. The gray area represents the area beyond ±3 % deviation, and the circular area represents the area within ±3 % deviation.

Table1 Specifications of SC3

Property	Value
Winding ratio, *n*	24:12:24 (2:1:2)
Size of Coil system, *d*	2 m
Coil Spacing, *s*	0 , ± 1 m (± 0.5 *d*)
Coil Resistance, *R*	5.8 Ω
Magnetic field at center, *B*	1,533 nT/A

Table2 Specifications of G2

Property	Value
Winding ratio, *n*	6 : 6 (1:1)
Size of Coilsystem, *d*	2 m
Coil Spacing, *s*	± 1 m
Coil Resistance, *R*	1.16 Ω
Magnetic flux density, *B*	4,013(nT/m)/A

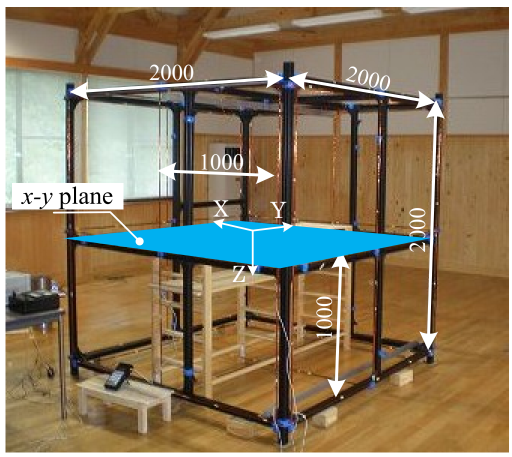


Fig.2 Geomagnetic field canceling system with a G2 coil system and three sets of an SC3 coil system. The specifications of SC3 and G2 are summarized in Table 1 and 2.

At 1 m distance, the circular area within ±3 % deviation was 1.2 m in diameter. It should be noted that the measured distribution of the x and y components has a slight gradient in the x-y plane.

2.2 Design

In the wooden building room, we constructed a geomagnetic field canceling system with three sets of SC3 coils as shown in Fig. 2. Because the measured geomagnetic field distribution had a slight gradient, a G2 coil system was also added. G2 consists of two same-sized square coil connected in differential. The specifications of the SC3 and G2 used are summarized in Tables 1 and 2. The coil frame is made of a nonmagnetic material, and the side length is 2 m. Four DC power supplies (R6243, ADVANTEST) were used for providing a current to the system.

2.3 Experimental results

Fig. 3 shows the experimental results of three sets of an SC3 coil system. The magnetic fields were generated to cancel the geomagnetic field at the center. The measuring plane is 1 m above the ground, and the gray area represents the area beyond ±1 μT. The circular area within 1 μT is 0.7 m in diameter, and that within 100 nT is 0.1 m in diameter. We can see that the x and y components have similar gradient profiles.

Fig. 4 shows the experimental results with a G2 coil system and three sets of an SC3 coil system. The gradient field were generated to cancel the gradient profile of the *x* and *y* components. The circular area within 1 μT is 1.2 m in diameter, and that within 100 nT is 0.4 m in diameter. Combined with the G2 coil system, we were able to expand the area within 100 nT.

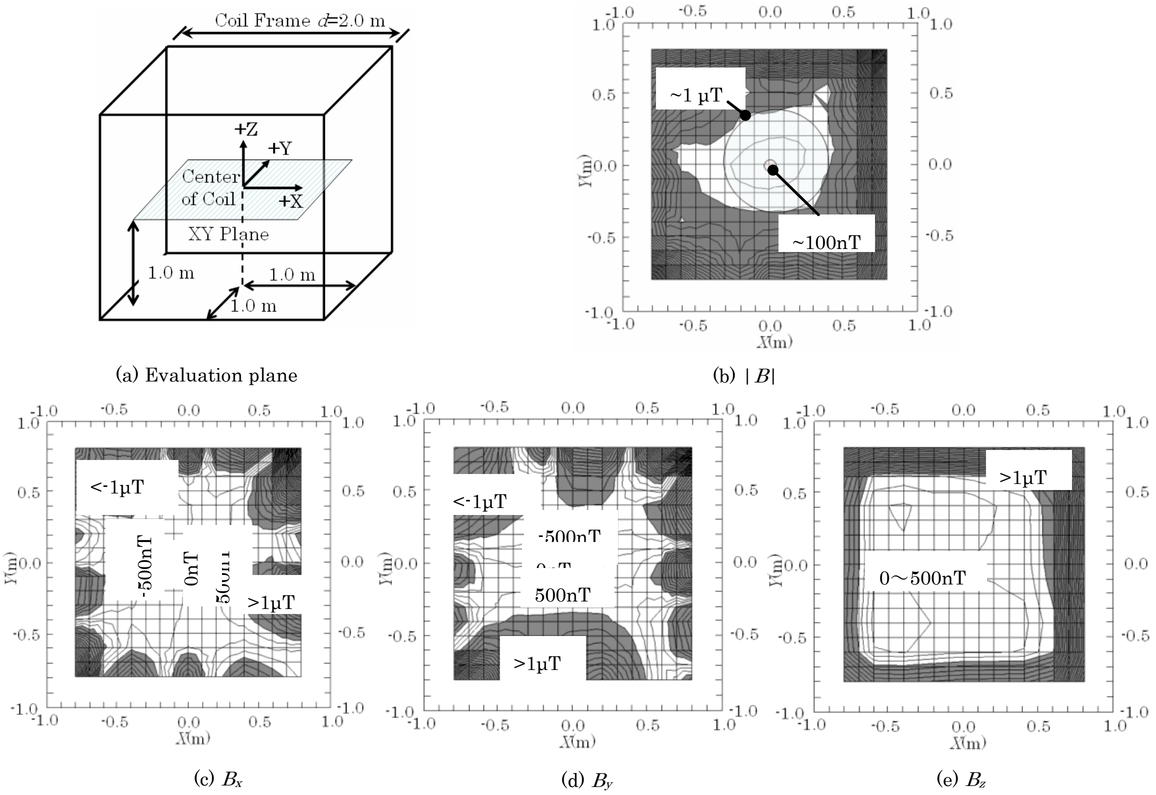


Fig.3 Measured distribution of the magnetic flux density with three sets of an SC3 coil system. Magnetic fields were generated to cancel the geomagnetic field at the center. The gray area represents the area beyond ±1 μT.

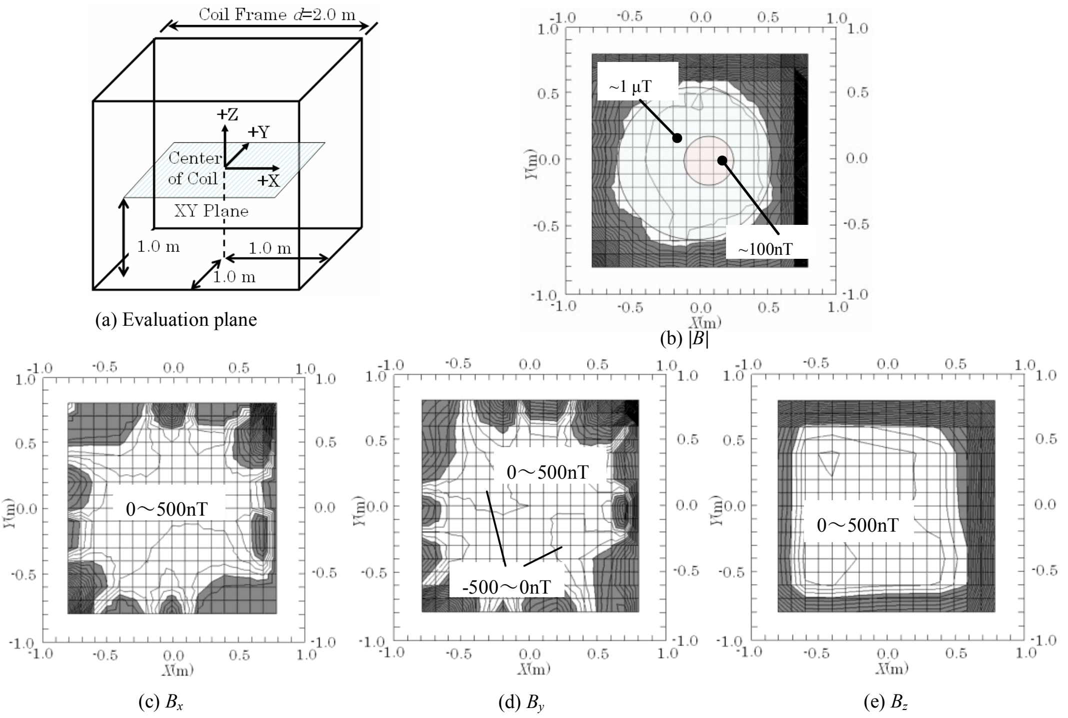


Fig.4 Measured distribution of the magnetic flux density with a G2 coil system and three sets of an SC3 coil system. A gradient field was generated to cancel the gradient profile of the x and y components. The gray area represents the area beyond ±1 μT.

3. FEM Analysis:

To demonstrate the residual magnetization measurements, we prepared a stepping motor for satellites. Fig. 5 shows the structure of the step motor. The size of the flange is 28 mm and the typical magnetic moment is 0.1 Am^2 [5]. Because of the structure, we can easily guess that the direction of the magnetic moment is parallel to the motor axis. We also confirmed the value of the magnetic moment with FEM software (JMAG, Nihon soken).

Fig. 6 shows the analysis model of the bare step motor, and Table3 shows the conditions of FEM analysis. The magnetic moment can be calculated with measured values of B_r or B_θ, as a function of the angle θ and as a parameter of distance between the motor and the measuring point r_x or r_{yz}. The relationships are described as follows.

$$M_{Br} = B_r \times 2\pi\, r_x^3 / (\mu_0 \cos\theta) \quad [Am^2] \qquad (2)$$

$$M_{B\theta} = B_\theta \times 4\pi\, r_{yz}^3 / (\mu_0 \sin\theta) \quad [Am^2] \qquad (3)$$

Where, M_{Br} is the magnetic moment M_B calculated with a measured value of B_r, M_{Br} is that of B_r, and μ_0 is the permeability of vacuum.

Fig. 7(a) shows an example of the calculated the values of B_r as a function of θ. The value of r_x is 0.5 m. We confirmed that the value of B_r was 150 nT at $\theta = 0$. Because the calculated results show a cosine curve, the profile of the magnetic flux leakage was axially symmetric. With the results, we calculated the values of M_{Br} using equation (2). Fig. 7(b) shows the values of M_{Br} as a function of θ. The simulated results show the calculated magnetic moment was 0.09 Am^2. The calculated the values of $M_{B\theta}$ were also agree with the results. We also confirmed these values as a parameter of r_x or r_{yz}. From the results, the bare step motor has M_B of 0.09 Am^2.

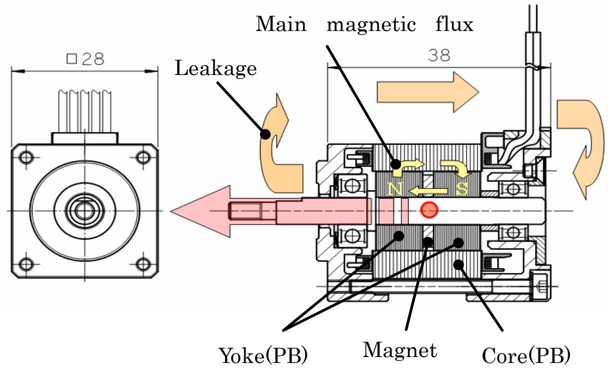


Fig.5 Structure of the step motor.

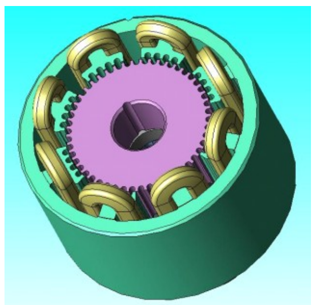


Fig.6 Analysis model the bare step motor.

Table3 Conditions of FEM analysis

Property	Value
Analysis software	JMAG, Nihon soken
Number of element	2150000
Material	Core and York : permalloy-30000 Magnet : REC24
Boundary condition	The air space is 50 times the model.

4. Residual magnetization measurements:

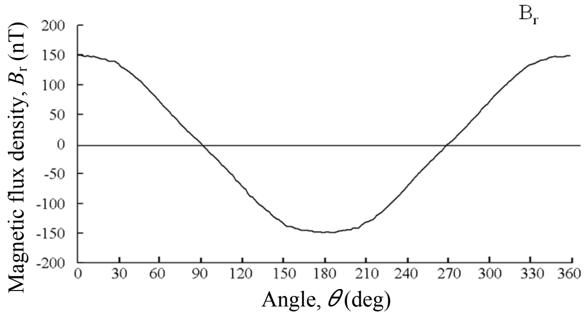
4.1 Bare step motor

Fig. 8 shows the definition of parameters for the residual magnetization measurements. In the geomagnetic field canceling system, we measured the magnetic moment with several distances and angles. If the distance is small, the calculated value of the magnetic moment depends on the angle. That means that the motor cannot assume a magnetic moment at the distance. After several investigations, we found a suitable distance, $r_x = 0.5$ m. Fig. 9 shows the experimental results. Measured values of B_r and B_z are clear sinusoidal curves as a function of the angle θ. Although the values are less than 1/100 as compared with the value of the geomagnetic field, the geomagnetic field canceling system allowed us to measure the existing weak magnetic fields. Estimated values of the magnetic moment approach 0.1 Am^2. The values are in agreement with the FEM results.

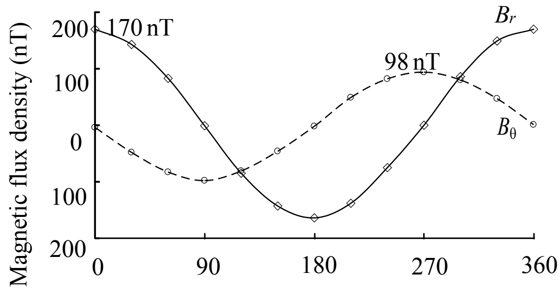
4.2 Step motor with U-shaped shells

In order to reduce the magnetic moment, we considered improving the magnetic circuit of the step motor. If the step motor is enclosed in a spherical shell with highly permeable material, the magnetic moment can be dramatically reduced. This is not practical solution because the motor shaft is also inside and the motor size is also limited for use in satellites. Here, we demonstrate one practical solution using a thin magnetic sheet (FINEMET, Hitachi). The sheet is only 0.12 mm thick, and the permeability for weak magnetic fields is high. Fig. 10(a) shows the schematic design of U-shaped shells made of FINEMET. The leakage of the magnetic flux passes through the shells, and the "one layer" consists of two U-shaped shells. The role of the shells is that of a bypass for the magnetic flux leakage. Fig. 10(b) shows the measured magnetic moment as a function of the number of the layer.

As a result, we succeeded in decreasing the magnetic moment to 1/3. The value of the measured magnetic moment became 0.03 Am^2, if the number of layers is six. However, there is no dramatic reduction of the magnetic moment when the number of layers is beyond seven. This may be a result of the residual magnetization of FINEMET.



(a) Magnetic flux density at r_x=0.5 m



(b) Moment of magnetism at r_x=0.5 m

Fig.7 The magnetic field analysis results of the step motor.

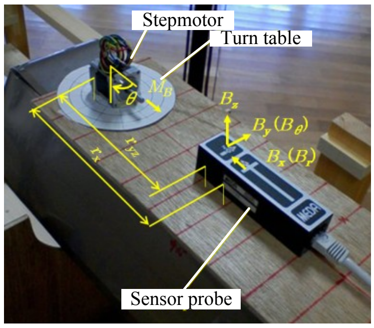
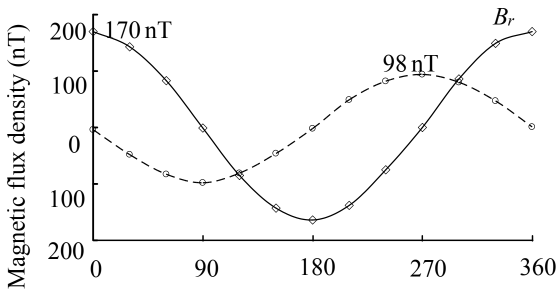
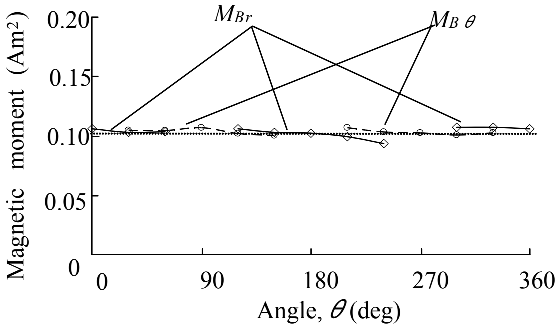


Fig.8 Definition of parameters for the residual magnetization measurements.



(a) Magnetic flux density at r_x=0.5 m



(b) Moment of magnetism at r_x=0.5 m

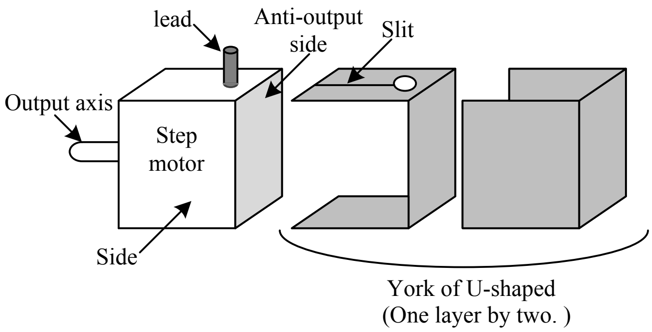
Fig.9 Experimental results of residual magnetization measurements. The distance between the step motor and FG sensor is 0.5 m.

5. Conclusion:

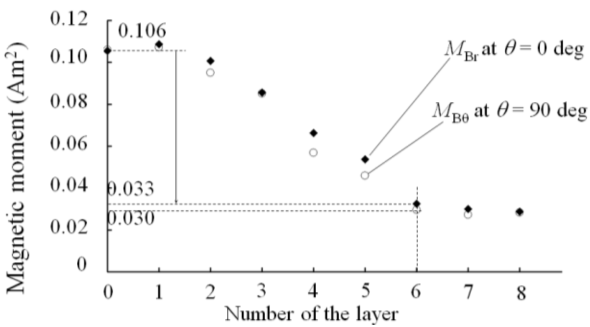
(1) A geomagnetic field canceling system consisting of same-sized square coils was developed. In a measured plane, a circular area within 1 µT had a diameter of 1.2 m, and that within 100 nT was 0.4 m in diameter.

(2) Magnetic moment measurements of a step motor were successfully demonstrated inside the system. The measured value of the magnetic moment was 0.1 Am^2, and it is in good agreement with FEM results.

(3) An approach to reduce magnetic field leakage from the step motor is also presented. It became possible to decrease the residual magnetic moment to 1/3 by adding an appropriate magnetic circuit.



(a) Schematic design of U-shaped shells



(b) Magnetic moment as a function of number of the layer

Fig.10 Effect of U-shaped shells on the measured magnetic moment.

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