The Modeling and Numerical Simulation for Sperical Vector-Potential Coil



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Abstract

We propose a model of the spherical vector-potential coil, and we investigate the properties of the coil especially for the uniform distribution of vector potential. The model is designed based on a structure in which thin toroidal coils superposed along a spherical surface. Rather than arranging the toroidal coils in close contact with each other along the surface of sphere, it is important that the layer spacing of the toroidal coils is constant so that the projection onto the axis of the sphere is equally spaced. When a current is applied to toroidal coils, no magnetic field is created outside of the toroidal coils, but a vector potential exists outside of the toroidal coil. If the same current is passed through each toroidal coil, the vector potential in the sphere becomes a uniform distribution by superposition. We show the properties of the coil, such as secondary voltage, and transimpedance. The simulation result confirms that the distribution of the vector potential is a uniform.

Vector-Potential Coil

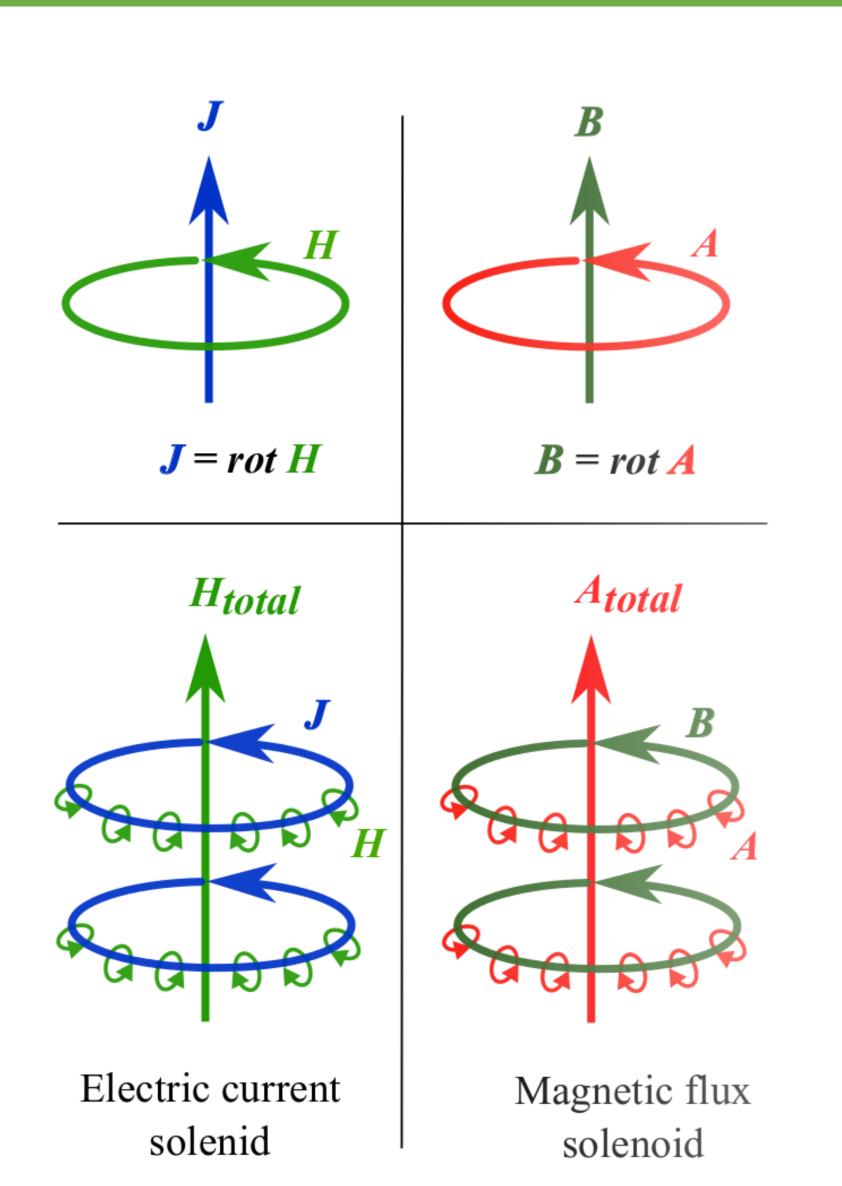


Fig. 1 Analogy between the electric current solenoid and the magnetic flux solenoid.

Based on Maxwell's equations to similarity of following of two equation, where J may correspond to B and H to A, respectively.

According to Ampere's circuital law is obtained:

$$\nabla \times \mathbf{B} = \nabla \times \mu_0 \mathbf{H} = \nabla \times \nabla \times \mathbf{A} = \mu_0 \mathbf{J}$$

Figure 1 shows, analogous to the fact that an electric current Figure 2 shows 3-D graphics. The model created a spherical solenoid coil J generates strong magnetic flux, if a magnetic vector potential coil by using the staking thin toroidal coils to flux solenoid is created, a vector potential A with uniform generate uniform vector potential which the return wire is not orientation is generated.

Motivation

- How to generate a uniform distribution of vector-potential using the spherical coil without magnetic field?
- Can we investigate the properties of a uniform distribution of the vector-potential coil using a new concept?
- Can we use a new concept of the time rate of change vector potential to produce the electric field with no electrode?
- * What is the properties of a uniform distribution of the vector-potential coil?

herical Vector-Potential Coil Design

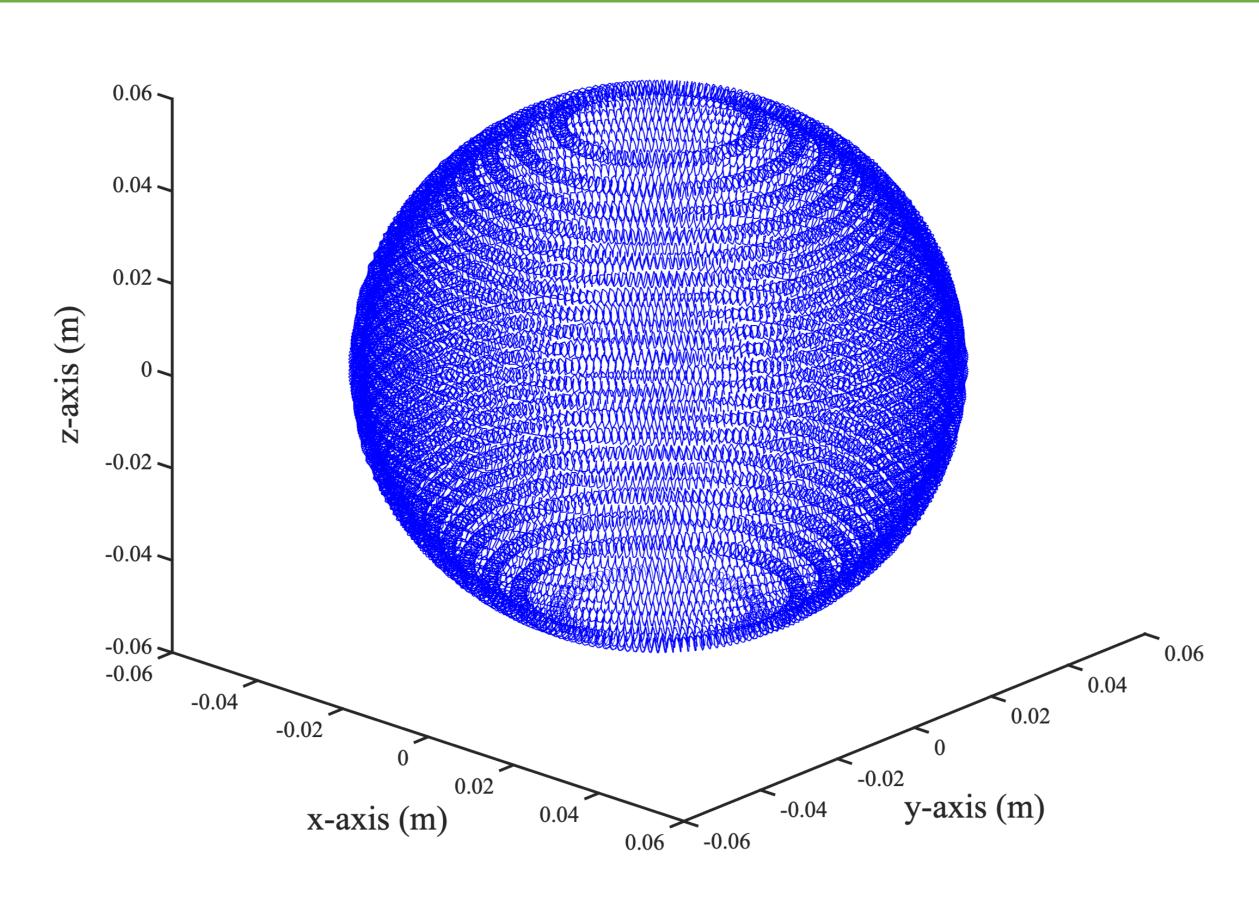


Fig. 2 The model of the spherical vector-potential coil by using MATLAB programing language.

drawn in this figure to avoid complexity.

Table 1 Specification of the spherical vector-potential coil.

Parameters	Symbol	Value
The current (A)	I	1.000×10^{-3}
Frequency (Hz)	f	10,000
The permeability of free space	$\mu_{\!\scriptscriptstyle 0}$	$4\pi \times 10^{-7}$
(H/m)		
The very long flexible solenoid:		
Radius of the solenoid (m)	r_0	1.505×10^{-3}
The cross-section area (m ²)	S	7.070×10^{-6}
Radius of the spherical coil (m)	R_{0}	52.500×10^{-3}
The number of turns per	n_0	770
unit length (turns/m)	7 . <i>T</i>	
The number of turns of coil (turns)	IV	34
The vector potential (Wb/m)	$A_z = rac{L}{4}$	$\frac{\iota_0}{4\pi} \int_{-R_0}^{R_0} I \frac{d\boldsymbol{z}}{\boldsymbol{r}}$

Numerical Simulation method

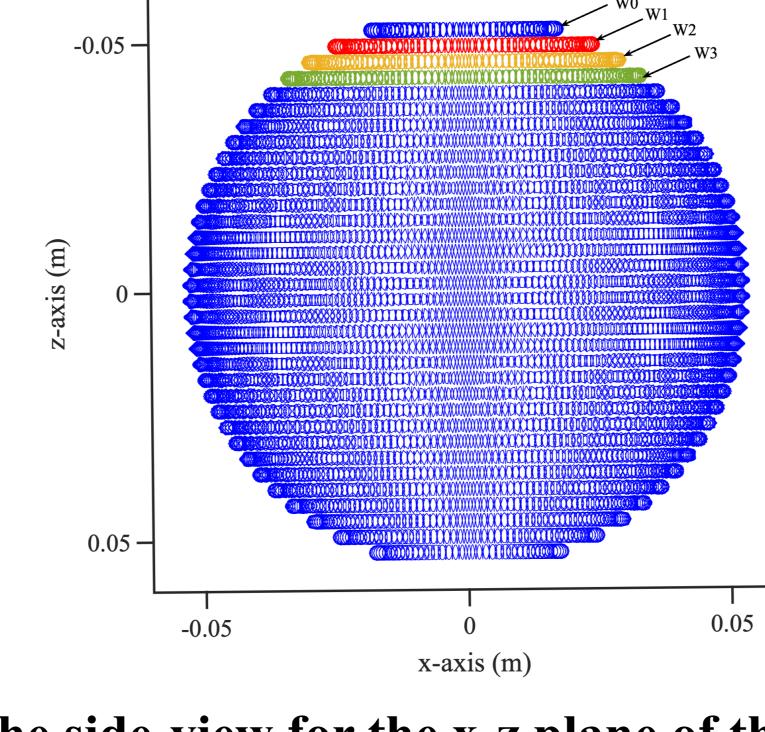


Fig. 3 The side-view for the x-z plane of the spherical coil.

The numerical simulation method, stacking concept is of the vector potential on the x-z plane passing through very important to investigate the properties of a uniform the central axis (y = 0). A uniform vector potential was vector-potential distribution in the spherical coil. When a very generated in one direction. long solenoid loop is driven by current. In this case, there is Because we assumed a Coulomb gauge with $\nabla \cdot A = 0$ in no magnetic field around the coil but the uniform vector- the space outside the sphere, the vector potential was potential distribution exists. The uniform distribution of continuous, and the directions of the inner and outer vector potential is generated using superimposed of stacking vector potentials were opposite.

To perform this simulation, the parameters in Table I were appears asymmetric, but it is an artifact on the computer used. As shown in Fig. 3, the thickness w of the toroidal coil graphics owing to the origin of the arrow, and the vector was constant, $2r_0 = w_0 = w_1 = ... = w_N$, and N = 34 layers potential is actually symmetric. of toroidal coils were stacked horizontally to form a spherical shape.

The coordinates of the element toroidal coil were calculated using parameter t in the following equation.

$$x_{i} = -\cos(2\pi t)(R_{0} + r_{0}\cos(2n\pi t))$$

$$y_{i} = -\sin(2\pi t)(R_{0} + r_{0}\cos(2n\pi t))$$

 $z_i = -r_0 sin(2n\pi t)$

$$n = n(X_i, Y_i, Z_i) = 2\pi n_0 R_0$$

where *i* is index of the toroidal coils.

In the entire spherical coil, the toroidal coil is arranged on a spherical surface so that projections in the z-axis direction are equally spaced. That is, on the surface of the sphere, the closer to the pole, the wider the interval between the toroidal coils.

The distance r between the coordinates (x_i, y_i, z_i) of the coil and the coordinates (X_i, Y_i, Z_i) of the observation point is as

$$r = \sqrt{(x_i - X_i)^2 + (y_i - Y_i)^2 + (z_i - Z_i)^2}$$

Results and Discussion

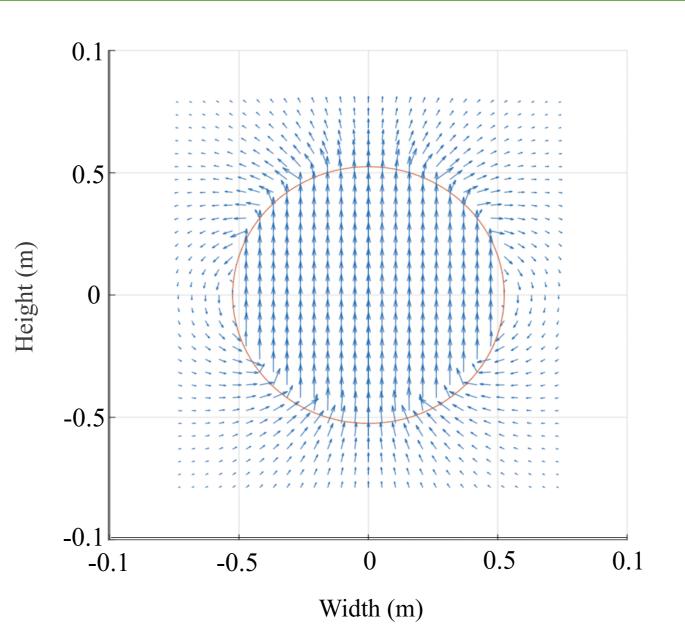


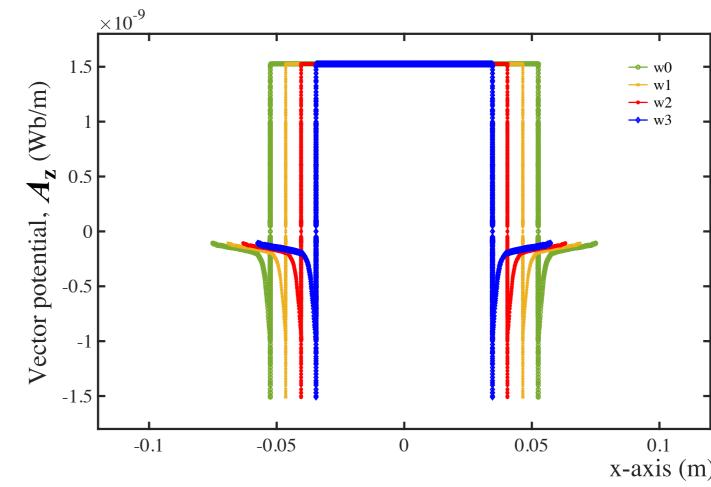
Fig. 4 Uniform distribution of vector-potential coil.

Figure 4 shows the simulation result of the distribution

projection with constant width in the parallel to z-axis.

Of note, the distribution near the surface of the sphere

The magnitude value of the uniform distribution of the vector-potential coil was 1.52×10^{-9} Wb/m.



vector potential along the x-axis direction at different latitudes. The legend, w0 - w3, corresponds to the position of the element toroidal coil in Figure 3.

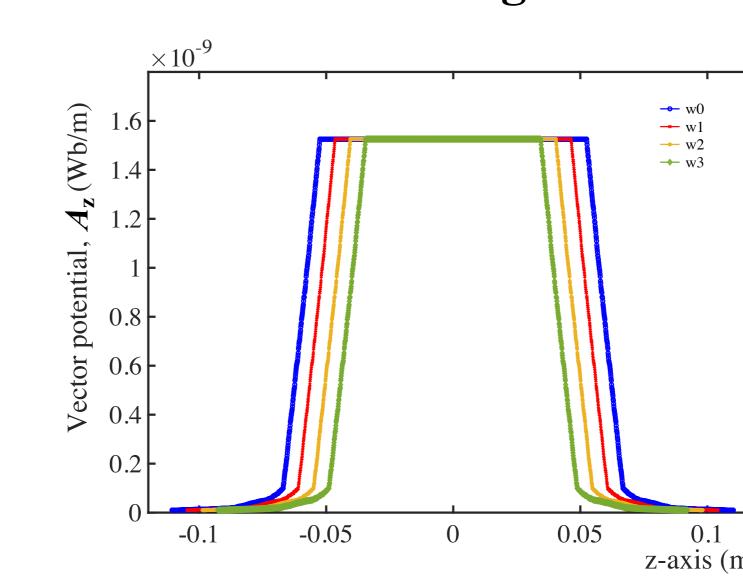


Fig. 6 Distribution of the z-axis component (A_z) of the vector potential along the z-axis direction at different x. 8(b). The transimpedance of this coil was $10.9 \text{ m}\Omega$. Legend w0-w3 corresponds to the positions of the element toroidal coil in Fig. 3.

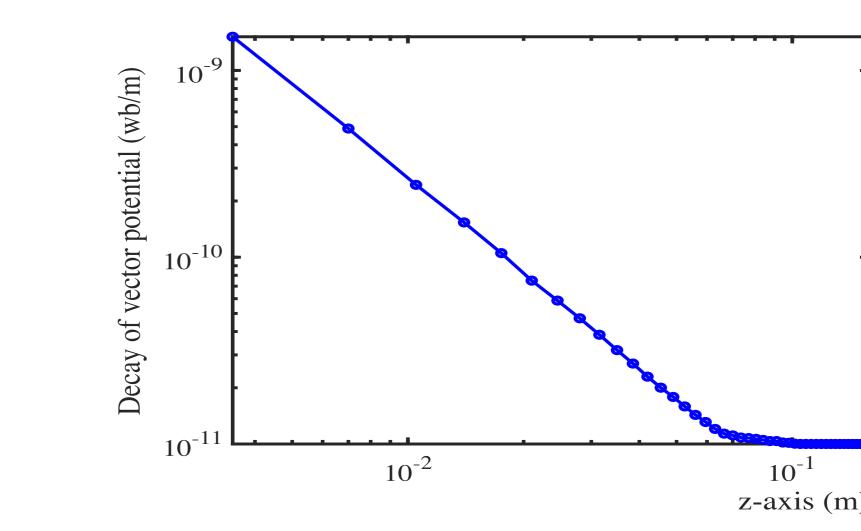


Fig. 7 Decay of the vector potential along the z-axis.

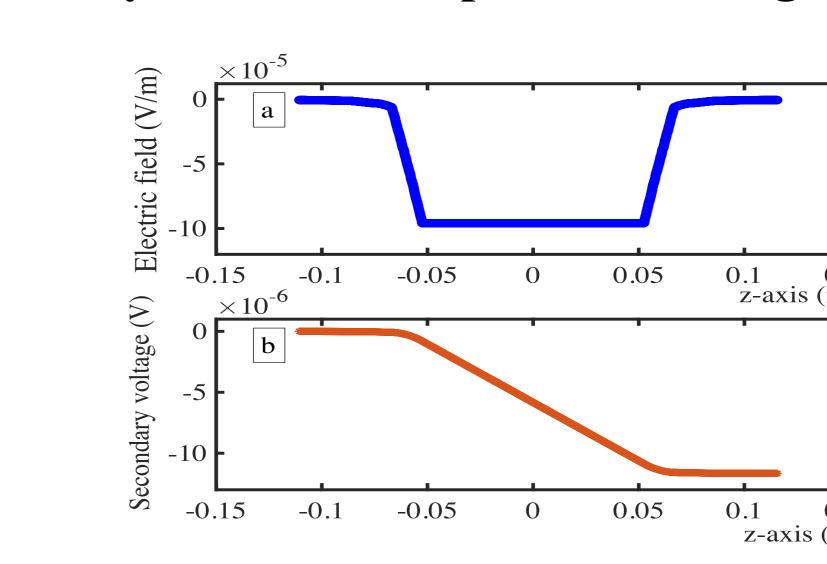


Fig. 8 Properties of the uniform distribution of the vector potential coil at f = 10 kHz; (a)electric field, and (b) secondary voltage, $(V = 1.09 \times 10^{-5} V)$

As shown in Fig. 5, the uniform distribution of vector potential is generated inside of the spherical coil. The direction of the vector potential is parallel to the spherical axis. Fig. 6 shows that the direction of the vector potential is opposite outside of the spherical coil, and the magnitude decreases with distance increasing under Coulomb gage condition of $\nabla \times A = 0$. Figure 7 shows the decay of the magnitude of the vector potential. The vector potential Fig. 5. Distribution of the z-axis component (A_z) of the -decays inversely with the distance as it moves away from the pole: $A_z \propto z^{-1}$ if $R_0 \leq z$. These result of the stacking thin toroidal coil using flexible solenoid with the same distance on the sphere surface, which the uniform distribution of vector potential is confirmed perfectly

> Properties of the uniform distribution of the vector potential coil is that the coil generates an electric field without electrodes, of which the magnitude is proportional to the time rate of change of the vector potential as shown in Fig. 8(a). The electric field had a phase of π / 2 ahead of the vector potential. There is no magnetic field both inside and outside of sphere vector potential coil. Even in this condition a secondary voltage can be induced the conductor which is passing through the spherical coil as shown in Fig

- The uniform distribution of vector-potential is generated by staking multiple toroidal coils on a sphere
- The distance between toroidal coils must be same each
- If the coil current change with time, uniform distribution of electric field can also be generated in the

Application

- * AC electric fields generation without requiring electrodes contact. For e.g. blood, living organism, deep sea water.
- Quantum phase control of spin-polarized atoms or electron such as atomic magnetometer, SQUID, spin Hall devices.

References

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