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Applications of Electromagnetic Phenomena in Electrical and Mechanical Systems
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Estimation of the current distribution in a cubic box by local magnetic field measurements

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ABSTRACT: A serious problem has been pointed out that the exciting magnetic field of induction heating cookers spread radiation, in order to heat the targets homogeneously. As a result, the target and its vicinity are heated and also exposed to high frequency magnetic fields. This leads to the investigation of visualizing the 3-dimensional magnetic field of the induction cooker.

Because of a large degree of layout freedom between the heating coils and targets, visualization of the three-dimensional (3D) magnetic field distributions around the induction cooker is a difficult task. This paper proposes a methodology based on an inverse approach for visualizing the magnetic field distribution around the induction heating coils. First, we solve the inverse source problem in order to identify the two dimensional (2D) current distributions from the locally 2D magnetic field measurement. Second, we compute the quasi-3D currents by combining the independently evaluated 2D currents. Major dominant current vector distribution is extracted by a threshold operation. Finally, after calculating the magnetic field distribution caused by the quasi-3D currents, we calculate the magnetic field distribution from the quasi 3D current vectored. An initial experiment proves the validity of our quasi-3D current visualization methodology.

1 INTRODUCTION

Recently, induction-heating systems are widely used for cooking and welding small cans because of their controllability as well as energy efficiency. Particularly, the induction cooking systems are widely used commercially and domestically because of their compactness and cleanliness. The induction heating cookers spread radiation in order to heat the targets homogeneously. This means that the cooks and their vicinities can be exposed to high frequency magnetic fields [1-3]. Thereby, it is essentially required to visualize the magnetic field around the induction heating coils to prevent accidental heating of the induction heating cookers.

Visualization of the 3D magnetic field around the induction cooker is a relatively difficult task for the existing analytical as well as numerical approaches, because the layout between the heating coils and the target has a large degree of freedom. Furthermore, numerous variations of the target shape, for example flat, round, convex and so on, cause confusion.

One of the ways to overcome this difficulty is to employ an inverse approach, which visualizes the 3D magnetic field distribution around the induction heating system after computing the exciting currents from only the locally measured magnetic field.

This paper proposes a methodology for visualizing the magnetic field distribution around the induction heating coils. Our method is composed of four major steps. First, the inverse source problems are solved in order to identify the 2D current distribution from the locally 2D magnetic field measurements [4-6]. Second, the distinctly evaluated 2D currents are combined in order to compute the quasi-3D currents. Third, the major dominant current vector distribution is extracted by a threshold operation. Finally, the magnetic field distribution caused by the quasi-3D current is calculated.

Thus, the entire magnetic field distribution around the induction-heating cooker can be visualized from the locally measured magnetic field. The basic principle and the initial experiments verify the usefulness of our approach.

2 QUASI-3D CURRENT VISUALIZATION

2.1 Modeling and formulation

Considering a cubic box containing the exciting coils, the 3D current distribution is evaluated by measuring the magnetic field perpendicular to each of the six surfaces. Direct solution of this problem is extremely difficult, because the currents distribute in all directions. This leads to carrying out a quasi 3D modeling of the current distribution.

Thus, we employ a locally 2D model, which assumes that the multi-layer surfaces with loop currents flowing, are parallel to the measured magnetic field [5,6]. Fig.1 shows a typical example of a loop current i and the measured magnetic field H.

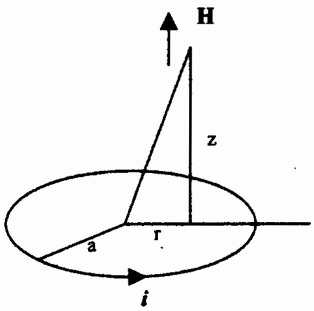


Figure1 A relationship between the loop current i and the magnetic field H.

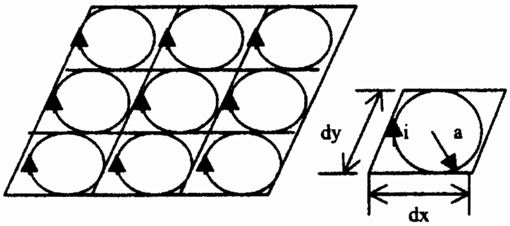


Figure 2 Loop current model on a layer located in parallel to a magnetic field measured surface.

A relationship between the loop current and the magnetic field is given in terms of the elliptic integrals $E(\kappa), K(\kappa)$ as:

$$H = \frac{1}{2\pi}\left[\frac{i}{\sqrt{(a+r)^2+z^2}}\right]\left[\frac{a^2-r^2-z^2}{(a-r)^2+z^2}E(\kappa)+K(\kappa)\right], \qquad (1)$$

where the parameters a, r and z are shown in Fig.1 and also,

$$\kappa^2 = \frac{4ra}{(r+a)^2+z^2}. \qquad (2)$$

Fig.2 shows one of the layer models. A relationship between the magnetic field vector **H** of a box surface and the loop current vector **I** of the layer is given by:

$$\mathbf{H} = C\mathbf{I}, \qquad (3)$$

where a square system matrix C is derived from Eq.(1). The current vector **I** can be evaluated by a simple inversion of C. This current evaluation is carried out independently to each of the layers and also to each of the surfaces of the box.

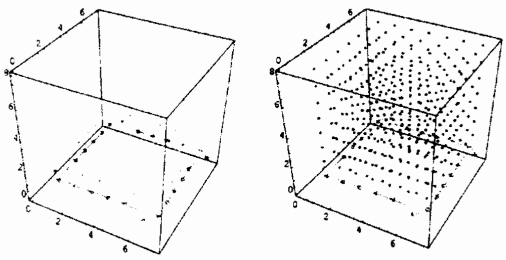
After computing the loop currents, the quasi-3D current vectors are composed, taking the flowing directions into account. The quasi-3D current distribution evaluated above contains some error. To remove the error, we carried out an intensive simulation to find a threshold value for extracting the significant current vectors.

2.2 Example of current vectors

Fig.3 shows the simulated current vectors:
a) the original current vectors
b) the significant current vectors extracted by the threshold operation

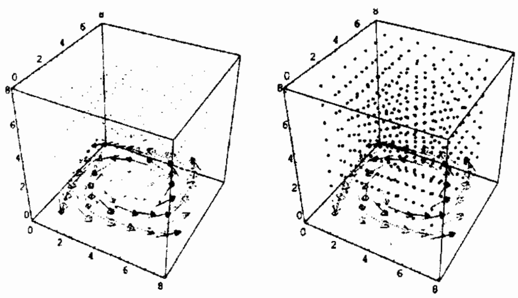
Fig.4 shows the experimental results, which have been computed from the field measurements to the three orthogonal surfaces of a $21\times21\times21cm^3$ box. The perpendicular magnetic fields were measured at 10 by 10 equi-spaced points on each of the box surfaces. Also, the exciting frequency was set to 30kHz, which was usually used to the induction heating cookers. The exact amplitude of the exciting current was 9A, while the computed one was about 11A. This is a very good agreement because our computation is not an exact 3D but the quasi-3D.

Fig.4 shows (a) the computed current vectors and (b) the threshold operated current vectors. The current vector distribution in Fig.4(b) surprisingly coincides with the shape of the experimentally used exciting coils.



(a) Original vectors (b)Significant vectors

Figure 3 the current vectors by simulation:
a) The originally evaluated current vectors
b) The threshold operated current vectors



(a) Original vectors (b)Significant vectors

Figure 4 the experimental current vectors:
a) The originally evaluated current vectors
b) The threshold operated current vectors

2.3 Example of magnetic fields

Fig.5 shows the 3D magnetic field distribution caused by the current vectors in Fig.4(b). From this result, it is obvious that the magnetic fields of induction cookers spread and cover the exciting coils.

Thus, the visualization of the 3D magnetic field and also quasi-3D current distribution can clarify the design as well as the usage policies of induction heating cookers.

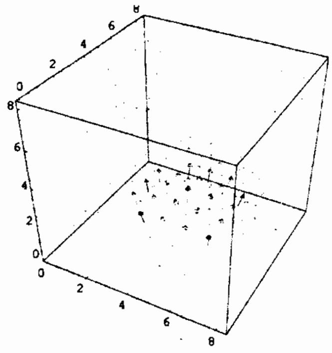


Figure 5 the magnetic fields distribution caused by the current vectors in Fig.4(b).

2.4 Tilted coil model

In this section, the visualization of the current distribution using a tilted coil is examined. Fig.6 shows the current distribution of the tilted coil model. Therefore, the quasi-3D methodology can be applied to the 2D as well as the 3D model. Fig.7 shows the significant vector after applying the threshold operation based on simulation.

Thus, we have made it possible to visualize the current distribution of a magnetic field source by using quasi-3D methodology.

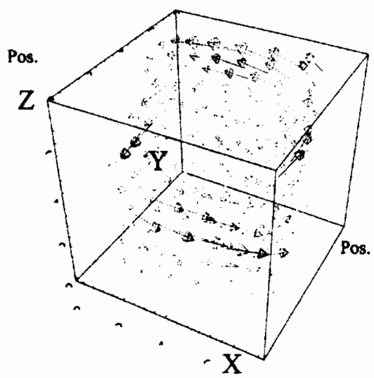


Figure 6 Current distribution by using the tilted coil model; the vectors are evaluated by the quasi-3D strategy.

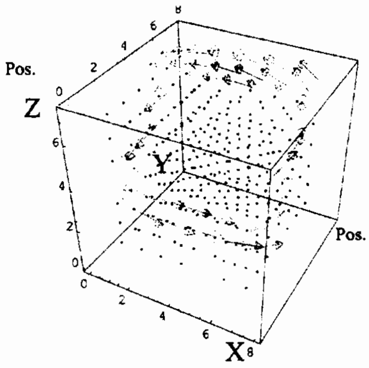


Figure 7 Current distribution by using the tilted coil model; the significant current vectors extracted by applying the threshold operation.

3 CONCLUSIONS

In the present paper, we have carried out the quasi-3D visualization of the currents by an inverse approach. Then, the 3D visualization of the magnetic fields has been investigated.

Thus, the visualization of the quasi-3D currents and of the 3D magnetic fields have pointed out the design as well as usage policies of induction heating cookers. The method proposed here can be applied to other physical vector fields.

4 REFERENCES

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