The Effect of Electrical Anisotropy and Acoustic Inhomogeneity in Magnetoacoustic Tomography with Magnetic Induction

Wanjiao Hou, Shuai Zhang, Ling Bai and Guizhi Xu

Province-Ministry Joint Key Laboratory of Electromagnetic Field and Electrical Apparatus Reliability, Hebei University of Technology, Tianjin, 300130, China, zs@hebut.edu.cn

***Abstract*—Magnetoacoustic tomography with magnetic induction(MAT-MI) is a noninvasive technology for imaging the distribution of electrical impedance in biological tissue. In the sameple, a time-varying magnetic field induces currents. A static magnetic field interact with the currents to produce a Lorentz force. Consequently, the sample will emit ultrasonic waves by the Lorentz force. The objective of this academic communication is to expound the effect of electrical anisotropy and acoustic inhomogeneity in MAT-MI.[1,2]**

***Index Terms*—MAT-MI, electrical anisotropy, acoustic inhomogeneity, forward problem, finite element method(FEM)**

I. INTRODUCTION

MAGNETOACOUSTIC tomography with magnetic induction(MAT-MI) is a noninvasive technology for imaging the distribution of electrical impedance in biological tissue. In the sameple, a time-varying magnetic field induces currents. The currents interact with a static magnetic field to produce a Lorentz force. Consequently, the sample will emit ultrasonic waves by the Lorentz force. It combines the good contrast of electrical impedance tomography with the high spatial resolution of sonography. Current research on MAT-MI technology for isotropic media are ignoring the electrical characteristics of conductivity anisotropy, and the conductivity associated with the eddy current, eddy current determine the acoustic source, the acoustic source in turn affect the acoustic pressure. Therefore, the study on the effect of electrical anisotropy and acoustic inhomogeneity has important significance in MAT-MI[1-2].

Since Henderson and Webster reported an impedance camera to generate the electrical impedance image of the thorax, it is of increasing interests to noninvasively measure the electrical impedance of biological tissues. Several approaches, such as electrical impedance tomography (EIT), magnetic induction tomography (MIT), magnetic resonance EIT (MREIT), magnetoacoustic tomography(MAT), and Hall effect imaging (HEI), have been developed to image the electrical impedance distribution. Among these technologies, EIT, MREIT, and MAT/HEI inject electrical currents into the imaging object through the surface electrodes, so that they have to face the "shield effect" caused by a low-conductivity tissue layer surrounding the object and therefore have difficulties in imaging the electrical impedance of deep biological tissue with high spatial resolution. MAT-MI excites the deep biological tissue with time-variantmagnetic field and measures the secondary magnetic field produced by the eddy current to reconstruct electrical impedance images. However, the inverse problem in MAT-MI, as in EIT, is an ill-posed problem[3-8].

It is well known that some biological materials, such as bone and skeletal muscle, are distinctly anisotropic. Recently, several studies have been developed to explore the effect of electrical anisotropy, such as the influence of white matter anisotropy on EEG source localization, inhomogeneous anisotropic cardiac tissues, and the effect of conductivity anisotropy on MAT-MI. Another study has reported that the diffusion anisotropy in breast cancer is significantly different from that in normal tissue. The water diffusion may have a relation with the electrical conductivity in a tissue, and the conductivity tensor can be obtained from the diffusion tensor. It is obvious that breast cancers may have different anisotropic conductivity tensor from that of normal tissues[9].

The tissue in most parts of human body, has heterogeneous acoustic properties, which leads to potential distortion and blurring of small buried objects in the impedance images. In the previous work, several MAT-MI algorithms were developed to reconstruct the distribution of acoustic source without considering acoustic speed variations in tissue. However, this assumption is not tenable in some applications, such as brain imaging, where the acoustic speed variation can be greater than 100%. In these cases, the reconstruction results will be deteriorated by blurring and displacement.

We utilized the finite element method to compute the induced eddy current in the forward problem of MAT-MI. Each element is considered as a point source and the center position of the element is considered as where it is located.

Most biological tissues contain components with different acoustic properties. The acoustic speed variation causes both blurring and displacement in the reconstructed image and reduces the contrast[8].

We analyze the principles of coupling problem of MAT-MI, including the two-dimensional axisymmetric transient electromagnetic field, displacement field, and sound field. The method adopts impulsing power source as the driving source, exciting coil generates alternating electromagnetic field which excites Lorentz force in the sample. The Lorentz force causes vibration of sample boundary, then acoustic waves is excited in the air. We can inverse the sample resistivity by detecting acoustic wave signal. The sound field distribution of the sample can be simulated through solving the equation which includes electromagnetic equation, wiener equation of elastic solids and sound field equation in the air[9].

II. METHODS

In a medium with a current distribution $\tilde{J}$ in a static magnetic field B_0, we have the following wave equation for the induced pressure $\tilde{p}(r,t)$,

$$\nabla^2\tilde{p} - \frac{1}{c_s^2}\frac{\partial^2\tilde{p}}{\partial t^2} = \nabla\cdot(\tilde{\mathbf{J}}\times\mathbf{B_0})$$

where $c_s = \sqrt{\frac{1}{\rho_0\beta_s}}$ is the acoustic speed, ρ_0 is the density of the medium at rest and β_s is the adiabatic compressibility of the medium.

$$p(r,w) = \int_R G_0(r,r_0)Q(r_0,w)dr_0 + \int_R G_0(r,r_0)f(r_0,w)p(r_0,w)dr_0$$

where Q is the acoustic source in the tissue due to induced Lorentz force and equals to $-\nabla\cdot(\mathbf{J}(r,t)\times\mathbf{B_0}(r,t))$. Here $p(r,w)$ is the acoustic pressure, G_0 is homogeneous Green's function[8].

$$\rho_0 \frac{\partial^2 \mathbf{u}}{\partial t^2} - \nabla\left(\rho_0 c_s^2 \nabla \cdot \mathbf{u}\right) = \tilde{\mathbf{f}}$$

$$\begin{cases} \frac{1}{\bar{c}_s^2}\frac{\partial p}{\partial t} - \frac{2\Delta c}{\bar{c}_s^3}\frac{\partial p}{\partial t} = -\rho_0 \nabla \cdot \mathbf{v} - \Delta\rho \nabla \cdot \mathbf{v} \\ \rho_0 \frac{\partial \mathbf{v}}{\partial t} + \Delta\rho \frac{\partial \mathbf{v}}{\partial t} = -\nabla p + \tilde{\mathbf{f}} \end{cases}$$

III. Simulation Study and Results

In the model of two-layered sphere, the inner radius is 0.03mm(r1=0.03mm), the outer radius is 0.06mm(r2=0.06mm).

$$\sigma_{1x} = 0.125\text{S/m}, \sigma_{1y} = 0.25\text{S/m}, \sigma_{1z} = 0.2\text{S/m}$$

$$\sigma_{2x} = 0.1\text{S/m}, \sigma_{2y} = 0.04\text{S/m}, \sigma_{2z} = 0.2\text{S/m}$$

$\sigma_{1x}, \sigma_{1y}, \sigma_{1z}$ is the conductivity of the inner sphere, $\sigma_{2x}, \sigma_{2y}, \sigma_{2z}$ is the conductivity of the outer sphere.

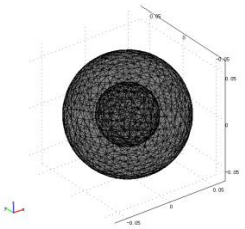

Fig. 1 The subdivision model of two-layered sphere

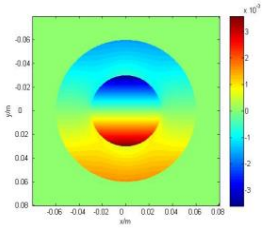

Fig. 2 Jx distribution at Z=0 Plane [A/m2]

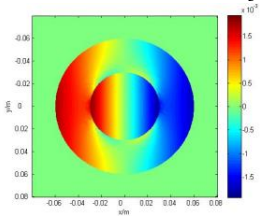

Fig. 3 Jy distribution at Z=0 Plane [A/m2]

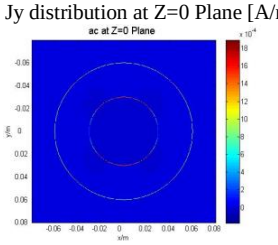

Fig. 4 acoustic source distribution at Z=0 Plane

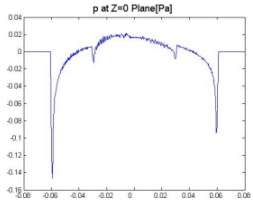

Fig. 5 acoustic pressure distribution at Z=0 Plane[Pa]

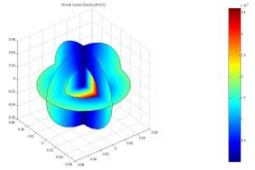

Fig. 6 Normal current density

IV. Conclusion

MAT-MI has been proposed as a technique to image electrical conductivity. Our results indicate that when imaging nerve or muscle, electrical anisotropy has a significant effect on the acoustic signal, and must be accounted for in order to obtain accurate images[7].

In these and other biomedical applications of PACT, the reconstructed images can contain significant distortions and artifacts if the inhomogeneous acoustic properties of the object are not accounted for in the reconstruction algorithm[10].

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V. References

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