ISSN 1750-9823 (print)
International Journal of Sports Science and Engineering
Vol. 03 (2009) No. 03, pp. 140-144

Imaging Method of New Magneto-acoustic Impedance Tomography with Magnetic Induction

Hui Xia +, Guoqiang Liu, Lingtong Jiang, Yanhong Li, Yang Zhang and Shiqiang Li

Institute of Electrical Engineering,Chinese Academy of Sciences, Beijing 100190,China

(*Received April 12, 2009, accepted June 25, 2009*)

Abstract. Magneto-acoustic tomography with magnetic induction (MAT-MI) is a new imaging technology, which making use of the coupling effect of the sound field, electric field and magnetic field to obtain an accurate conductivity distribution of the measured organization to achieve non-destructive detection. MAT-MI can display the change of human organs during physical activities, and discovery the pathologic reaction of the measured organization in time, so it can supply prospective information for people. This method has application prospect in many respects, such as non-invasive detection, early diagnosis, continuous monitoring and so on. In this paper, copper sheet is selected as experimental sample. Firstly, propose the multi-physics fields coupling calculation method based on two-dimensional axisymmetric transient model, includes electromagnetic field, displacement field and sound field, and calculate out the simulation result of sound field. Then according to the simulation result, build acoustic wave detection circuit, and design detection experiment. The coherence of experimental results and simulation results not only verify the correctness of theoretical analysis, but also illuminate the feasibility of the method, and establish the foundation for clinical medical study.

Keywords: magneto-acoustic tomography with magnetic induction(MAT-MI), Multi-physics fields coupling, Copper sheet sample, acoustic wave detection

1. Introduction

Electrical impedance tomography (EIT) is a new direction for biomedical imaging technique. The variation of human tissue when doing physiological activity(e.g. respiratory or heartbeat) will be shown with EIT, not only could continuously monitor the physiological activity of cardiovascular, gullet, stomach and so on, but also could discovery the pathologic change of human tissue(e.g. carcinogenesis[1] or brain edema), so this technique has important application value and comprehensive development foreground in human physiological function research, disease diagnose and daily health care[2][3][4]. As a kind of functional imaging, EIT has many predominance compared with conventional imaging means, such as non-invasive diagnose, high imaging quality and so on. But EIT has not been used in clinical application because of it's low resolution now [5]. In order to resolve the problem, Magnetoacoustic tomography with magnetic induction (MAT-MI) is proposed by Bin He et al [6], which is shown in Fig. 1. In MAT-MI, a imaging target is placed in a static magnetic field with pulsed magnetic stimulation imposed on it, the pulsed current induces eddy current in the sample, and the induced eddy current in static magnetic field generates Lorentz force. The Lorentz force causes acoustic vibration, and the generated acoustic wave can be measured around the sample to reconstruct the conductivity distribution of the sample.

At present, MAT-MI is at its' initial stage [6][7][8], there are several universities and research institutions studying MAT-MI, include Minnesota University, Zhejiang University, Central South University for Nationalities, Institute of Electrical Engineering, Chinese Academy of Sciences and so on. Bin He and his co-workers have been proposed the assumption of the piecewise smooth and developed the mechanical rotation method based on the hardware system to analysis the image reconstructed algorithm of electromagnetic field inversion problem. Using this method, the computing needs many steps, then the imaging speed is decelerated, so the practical application of the MAT-MI technology encountering enormous obstacles.

+ Corresponding author. Tel.: +86-010-82547189; fax: +86-010-82547189.
E-mail address: xiahui@mail.iee.ac.cn.

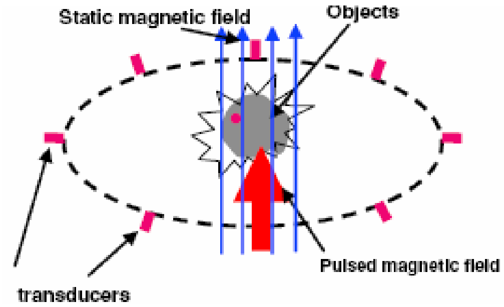

Fig. 1: The illustration of MAT-MI(quoted from[6])

G. Q. Liu and H. Wang put forward a non-contact MAT-MI method based on single component Lorentz force density[9]. The technology can improve the resolution of image and does not require rotating magnetic field. But because the hardware system still need magnet devices, the structure of the hardware system become more complex and the cost become higher. In order to resolve these problems, propose a new non-magnet MAT-MI method. In this paper, copper sheet is selected as test sample. Firstly, put forward the multi-physics coupling calculation method based on two-dimensional axisymmetric model, includes transient electromagnetic field, displacement field and sound field, and calculate out the simulation result. Then, according to the simulation model, build the acoustic wave detection hardware experimental system and perform the experiment, which establish the foundation for clinical application of this technology.

2. The Numerical Method of Multi-physics fields coupling

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 multi-physical equation which includes electromagnetic equation, wiener equation of elastic solids and sound field equation in the air.

The exciting coil is hollow cylindrical coil, and round copper sheet is selected as the sample, the simulation model has axial symmetry, so the vector magnetic potential $\bar{A}$ only has circumferential component, labeled as A, the corresponding axisymmetric electromagnetic equation is:

$$\frac{\partial^2 A}{\partial^2 r}+\frac{1}{r}\frac{\partial A}{\partial r}-\frac{A}{r^2}+\frac{\partial^2 A}{\partial^2 z}-\mu\sigma\frac{\partial A}{\partial t}=-\mu J_s \quad (2.1)$$

Where μ is magnetic permeability, σ is electrical conductivity, and J_s is current density of the exciting coil. Although the current density of the exciting coil generates only circumferential component, magnetic flux density includes radial and axial component, we can get

$$J=-\sigma\frac{\partial A}{\partial t}$$
$$B_r=-\frac{\partial A}{\partial z}$$
$$B_z=\frac{\partial A}{\partial r}+\frac{A}{r} \quad (2.2)$$

According to the solving range of the Fig 2a, we can see that Ω1 is the air range, Ω2 is the sample position, Ω3 is the exciting coil position. In the Ω1 area, conductivity equals zero, and there is no exciting source. In the Ω2 area, there is also no exciting source. In the Ω3 area , the current in the coil is the source current.

At the symmetry axis and infinity boundary, the boundary condition is that A equals zero. We can calculate the formula (2.2) by solving A. We can get

$$\vec{F}_s=\vec{J}\times\vec{B} \quad (2.3)$$

Then, according to the theory of continuum mechanics, the wiener equation of elastic solid can be derived through using momentum conservation principle, law of conservation of mass and constitutive equation of mechanical properties in an inertial reference frame. The vector form of the wiener equation can be wrote as

$$\rho\frac{\partial^2\vec{u}}{\partial t^2}=G\nabla^2\vec{u}+\frac{G}{1-2v}\nabla(\nabla\cdot\vec{u})+\vec{F} \tag{2.4}$$

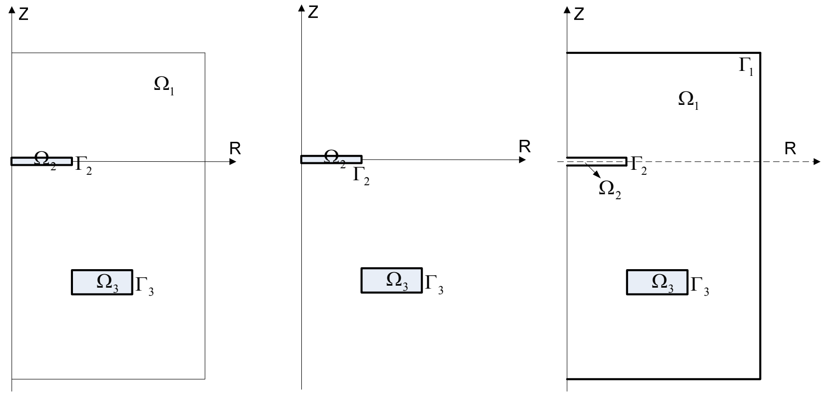

Fig. 2: Solving models

(a) Electromagnetic field solving model (b) displacement field solving model (c) Sound field solving model

Where $\vec{u}=u(r,z,t)$ is displacement field, $\vec{F}$ is unit volume force, ρ is density of copper sheet, G is shear modulus, and v is Poisson's ratio. The solving range is shown in figure 2b, the boundary conditions can be wrote at the Γ_2 and Γ_3

$$\vec{F}=-\vec{n}_s p \tag{2.5}$$

Where $\vec{n}_s$ is unit normal vector which pointing the outside of the sample or coil. In the experiment, because there is no Lorentz force in the air, the acoustic wave equation in the solving range of Fig 2c can be wrote as

$$\nabla^2 p-\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}=0 \tag{2.6}$$

In the cylindrical coordinate, we can get

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}-\frac{1}{r}\frac{\partial p}{\partial r}-\frac{\partial^2 p}{\partial r^2}-\frac{\partial^2 p}{\partial z^2}=0 \tag{2.7}$$

Where the boundary condition is r=0 at the axis of symmetry, and p=0 at the infinite point. On the Γ_2 and Γ_3, the boundary condition are as follows,

$$\vec{n}\cdot\nabla p=\vec{n}\cdot\frac{\partial^2 u}{\partial t^2} \tag{2.8}$$

According to the formula (2.4) ~ (2.8), we can solve the sound wave distribution in the sound field of the sample. In the simulation process, the waveform of exciting current can be shown as follow

$$I(t)=\frac{V_0}{\omega L}e^{-\alpha t}\sin(\omega t) \tag{2.9}$$

where discharge voltage $V_0=1000V$, induction L=7.7μH, resistance R=8.06e-3Ω, capacity C=200μF, α=R/2L, $\omega=\sqrt{1/(LC)-\alpha^2}$. In the course of practical application, the current waveform is intercepted by a thyristor, and only reserves the first positive spike. The impulse width is about 120μS, numerical simulation result of sound field distribution at 60μS is shown below in Fig.3. From Fig.3, we find that the frequency of acoustic wave signal mainly concentrate in the range of 3-5 KHz in the spherical sound field range whose center is the sample's center and radius is approximately 0.005m.

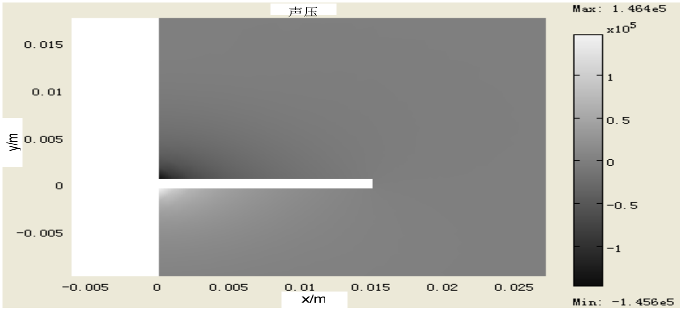

Fig.3: At the time of 60μs, sound field distribution

3. Experiment

3.1. Acoustic detection experiment

We adopt the experimental system shown in Fig.4 to detect the sound field of the copper sheet sample. During the detecting, ambient noise besides acoustic field interference generated by exciting coil itself can be detected by high sensitive microphone, and coupled in acoustic wave caused by the sample's vibration to influence the sensitivity of signal detection, so shield configuration must be adopted to eliminate ambient noise and other interference in order to ensure the authenticity of the detected signal. Therefore, we affix the ultrathin acoustic material in the inner surface of the sealed plastic containers. In order to compare with the simulation results, the sample that all experiment used is the same with that used in simulation, the thickness of round sheet copper is 1mm, and its' radius is 15mm. At the same time, we must ensure that the copper sample is coaxial with the exciting coil, and the distance between them is 20mm.

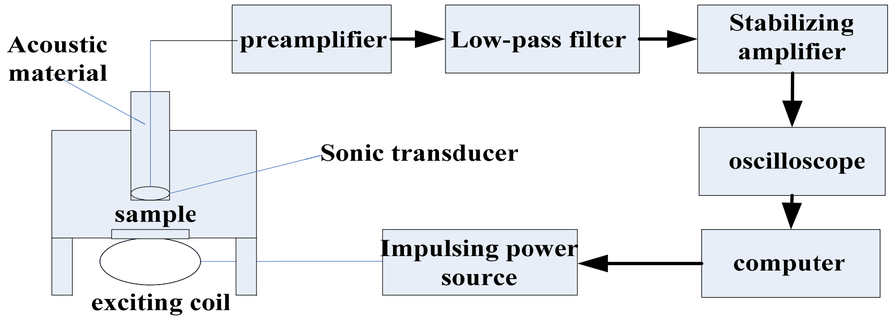

Fig.4: New MAT-MI hardware system block diagram

3.2. Experiment results and analyze

In the spherical sound field range whose center is the sample's center and the radius is approximately 0.005m, the acoustic signal under excitation is detected. Then we process the detected sound signal by FFT, and obtain signal spectrum. The result is shown in Fig.5

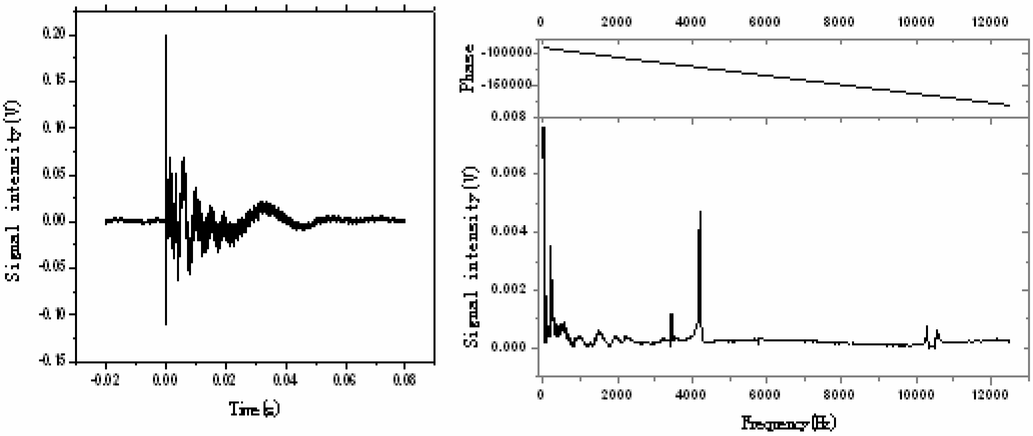

Fig.5: detected acoustic wave signal and it's spectrum

As shown in Fig.5, in the spherical sound field range whose radius is approximately 0.005m, the frequency of detected sound wave signal mainly concentrate in the spectrum range of 3-5KHz, it is consistent with the simulation results. It proves that the simulation method of multi-physical field coupling is correct, the method of MAT-MI is feasible, and it establishes the theoretical foundation of human tissues detection using the method.

4. Conclusion

Medical imaging is a research domain with broad development prospect, it is essential to the advancement of medicine and improvement of people's life. In this paper, we adopt a new technique without magnet, it uses the coupling effect of sound field and electromagnetic field to realize the non-destructive detection of the sample, and finally obtain the conductivity distribution of the measured sample. Firstly, put forword the calculation method of multi-physical field coupling, and simulate the sound field's distribution. Then, design the hardware experiment system, and perform the acoustic detection experiment. The consistency of measured result and simulation result proves the correctness of theoretical analysis, and provides reference and guidance for the quantitative acoustic signal detection and the sample conductivity inversion algorithm to be researched next. The technique is to play an important roll in human physiological function research, disease diagnosis and day-to-day health care.

5. Acknowledgements

The authors thank the National Natural Science Council of China for financial support (Grant No.60802086 and Grant No. 50977084) and the National High Technology Research and Development Council of China (Grant No. 2007AA06Z212).

6. References

[1] V. Cherepenin et al. A 3D electrical impedance tomography (EIT) system for breast cancer detection[J]. *Physiol. Meas.*. 2001, **22**(1): 9~18.

[2] J. P. Morucci and B.Rigaud. Bioelectrical impedance techniques in medicine part III: Impedance imaging third section: Medical applications[J]. *Crit. Rev. Biomed. Eng.*. 1996, **24**(4-6): 655~677.

[3] I.Frerichs. Electrical impedance tomography in applications related to lung and ventilation: a review of experimental and clinical activities[J]. *Physiol. Meas.* 2000, **21**, R1~R21.

[4] X. Z. Dong. The development of the bioelectric impedance technologies [J]. *Chinese journal of medical physics.* 2004, **21**(6): 311~317.

[5] A. D. Seagar, D. C. Barber, B. H. Brown. Theoretical Limits to Sensitivity and Resolution in Impedance Imaging[J]. *Clin. Phys. Physiol. Meas.*. 1987, **8**: 13~31.

[6] X. Yuan, B. He. Magnetoacoustic Tomography with Magnetic Induction (MAT-MI)[J]. *Phys. Med. Biol.*. 2005, **50**: 5175~5187.

[7] Q. Y. Ma and B. He. Investigation on magnetoacoustic signal generation with magnetic induction and its application to electrical conductivity reconstruction[J]. *Phys. Med. Biol.*. 2007, **52**: 5085~5099.

[8] Q.Y. Ma and B. He. Magnetoacoustic Tomography With Magnetic Induction: A Rigorous Theory[J]. *IEEE transactions on biomedical engineering.* 2008, **55**(2): 813~816.

[9] G. Q. Liu, H. Wang et.al. Reconstruction Method of Magnetoacoustic Tomography with Magnetic Induction (MAT-MI)[J]. *13th International Conference on Electrical Bioimpedance combined with the 8th Conference on Electrical Impedance Tomography*. 2007, pp. 312~314.