Magnetoacoustic Tomography with Magnetic Stimulation (MAT-MS)

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Abstract—**We have proposed a new imaging modality, magnetoacoustic tomography with magnetic stimulation (MAT-MS) to image the electrical impedance distribution. In this paper we report out pilot experimental study. In MAT-MS, the tissue is put in a static magnetic field and a pulsed (μs) magnetic field. The pulsed magnetic field induces eddy current in the tissue. Consequently, the tissue will emit ultrasonic waves by the Lorenz force. The acoustic signals are collected around the object and processed to reconstruct the electrical impedance distribution in the tissue. A pilot experiment was conducted and we observed the signals from point metal objects and metal wire loops.**

Keywords—**Magnetoacoustic tomography, magnetic stimulator, electrical impedance imaging, conductivity**

I. Introduction

Electrical impedance tomography (EIT) has been pursued to noninvasively estimate information regarding distribution of electrical impedance within the body. However, the spatial resolution of conventional EIT is poor. We propose a new approach called magnetoacoustic tomography with magnetic stimulation (MAT-MS) with the aim of imaging the impedance distribution with high spatial resolution. It combines ultrasound with magnetic field. In MAT-MS (Fig. 1), the tissue is put in a static magnetic field and a pulsed (μs) magnetic field. The pulsed magnetic field induces eddy currents in the tissue. Consequently, the tissue will emit ultrasonic waves due to the Lorenz force produced by the combination of the eddy current and the static magnetic field.

There are two other imaging modalities similar to MAT-MS: EIT [1] and Hall Effect Imaging (HEI) [2-5]. EIT is poor in spatial resolution. HEI is another form of MAT, but the current is injected into tissue by applying two electrodes on the surface of the sample. In MAT-MS, a magnetic stimulator (MS) is used to generate a pulsed current. MS has been used in research and clinical environment [6-8]. Compared with the other similar imaging modalities, MAT-MS has several unique features. Firstly, it combines the good contrast of EIT with the good spatial resolution of ultrasound. Secondly, it has good imaging depth, because it uses magnetic field to generate acoustic waves, and magnetic field can go into tissue deeply. Thirdly, it will not be affected by the low-conductivity layer of tissue at/near the surface of human body, such as the skull of the head and the fat layer on the breast. This is because the magnetic field can go into the low-conductivity layer easily, while the electrical current will not. At last, the E induced by a pulsed B in MAT-MS is a solenoid field, while the field in Hall Effect Imaging (HEI) and EIT are irrotational E. Furthermore, this technique is compatible with MRI.

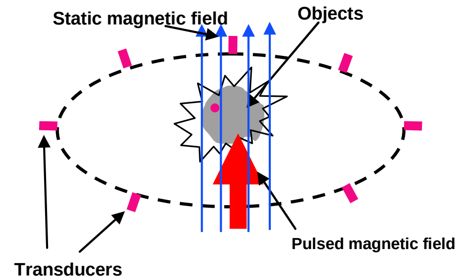

Fig. 1 Illustration of MAT-MS.

II. Methods

The acoustic wave in MAT-MS obeys the following equation [9,10]

$$\nabla^2 p - \frac{1}{c_s^2}\frac{\partial^2 p}{\partial t^2} = \nabla \cdot (\mathbf{J} \times \mathbf{B}_0), \quad (1)$$

where p is the acoustic pressure, c_s is the acoustic speed, $\mathbf{J}$ is the eddy current, and $\mathbf{B_0}$ is the static magnetic field. Since

$$\mathbf{J} = \sigma \mathbf{E}, \quad (2)$$

where σ is the electrical conductivity of the object and $\mathbf{E}$ is the electrical field. In the above equation, we have ignored the displacement current $-\partial \mathbf{D} / \partial t$, because the ratio of displacement to conduction current is on the scale of $\omega\varepsilon / \sigma$ [11], where ε is the permittivity of the sample (~10^{-9} F/m in biological tissue) and ω is the frequency, and the ratio is in the scale of 0.001 at the MHz range in the biological tissues. The above two equations can be used to produce the signal in the forward problem of numerical simulation and to derive the reconstruction algorithm. However, in this paper, we will only focus on some experimental aspects.

In our experiments, we use an unfocused transducer with a central frequency of 1 MHz and a diameter of 13 mm. It points horizontally to the sample. For good coupling of acoustic waves, both the transducer and the sample are immersed in water. A home-made magnetic stimulator transmits magnetic pulses with a width of 2 μs. The coil of the magnetic stimulator has a diameter of 80 mm. A permanent magnet (50 mm by 50 mm by 25 mm) is put under the sample. The permanent magnet can create a magnetic field with a flux density of about 0.1 T at 1 cm from its surface. A function generator is used to trigger the magnetic stimulator, control its pulse length, and synchronize the oscilloscope sampling. The signal from the transducer is first amplified through a pulse preamplifier, then recorded and averaged 100 times by an oscilloscope. A personal computer is used to control the step motor for rotating the sample and transferring the data. A multifunctional card in the computer acts as the function generator, oscilloscope, and part of the driver for the stepper motor.

III. RESULTS

Firstly, we used a copper stripe with a section of 1 mm by 4 mm as the sample. Fig. 2 shows the signals after high-pass filtering. When we moved the copper back and forth, the peak also moved accordingly, as shown by comparing the two figures in Fig. 2. The arrival time of the signals equals the distance between the detector and the copper stripe divided by the acoustic speed in water. We also moved the detector around the copper. In most positions, we could detect the signal from the copper although the amplitude of the signal varied. Basically, the amplitude of the signal increased when the detector moved closer to the object.

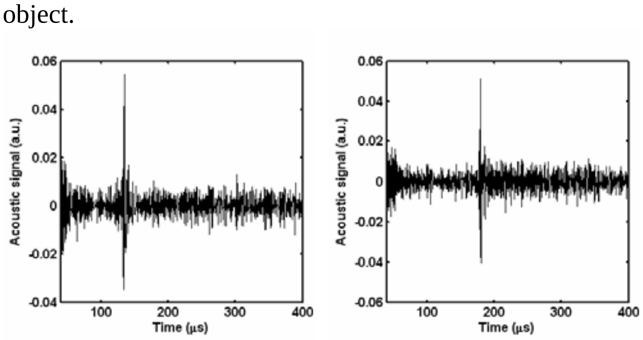

Fig. 2 The signal from a metal stripe after high-pass filtering.

We also imaged a metal loop to test if our device can image an object with a shape. We chose a wire loop to reduce the effect of acoustic heterogeneity. Fig. 3 shows the signal. There are two major peaks with a time delay of about 30 μs, which matches with the distance between the front and rear boundary of the loop when looking from the position of the transducer. This shows that the two major peaks correspond to the two boundaries. When we move the detector around the object, the signal looks similar except that the time delay between the two peaks is different. These results show that it is promising to obtain an image of the metal wire. We are building a scanning system to collect the acoustic signals around the object.

IV. DISCUSSION

We have proposed the magnetoacoustic tomography with magnetic stimulation (MAT-MS) and conducted a pilot experimental study to test its feasibility. By combining ultrasound with magnetic field, MAT-MS is expected to have the good contrast of EIT and the good spatial resolution of ultrasound. In the pilot experimental studies, we have observed the signals from point metal objects and metal wire loops. The MAT-MS signals from biological tissues will be studied in future investigations.

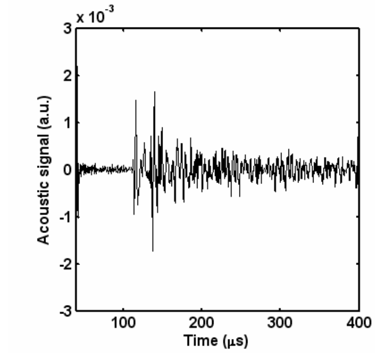

Fig. 3 The signals from a metal wire loop.

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