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Multi-frequency Electrical Impedance Tomography System for Non-Destructive Crack Detection

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1. Introduction

Electrical Impedance Tomography (EIT) is an imaging modality which reconstructs the impedance distribution of a closed domain using the measured boundary voltage data when injecting current [1-6]. It has been applied to numerous industrial applications such as: process tomography [7], nondestructive testing [8], imaging biological cells [9], medical imaging equipment [4] etc. Among them, non-destructive testing (NDT) of a structures is one of the important issues to evaluate their safety level [10]. Specially, crack and delamination of the structure such as a pipe, concrete and system component must be detected and monitored in the nuclear power plant and high level radioactive waste repository site. Multi-frequency conductivity and permittivity information can provide the improved crack identification in the complex structure including many cracks and rebar.

In this study, we introduced some simulation and experiment results for a phantom to check its feasibility of non-destructive crack detection.

2. Methods and Results

In this section problem definition, computer simulations and phantom experimental results are described briefly.

2.1 Problem Definition

When the current is injected into a subject through the electrodes attached at the boundary of it in fig. 1, the current and electromagnetic flux densities are distributed inside the domain, Ω, where κ means the spatial distribution of impedance. In case where any change in κ occurred in Ω, the inside electromagnetic fields and the boundary values are also changed.

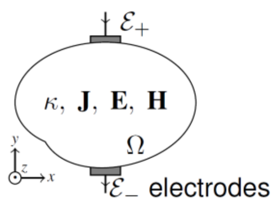


Fig. 1. A model with surface electrodes for EIT

Many algorithms are developed to reconstruct the distribution of impedance in Ω by using the relation between the boundary voltage measurements and injected currents [11-12]. But, this inverse impedance reconstruction problem has difficulties from its inherent ill-posedness and nonlinearity. We focus on the detection of location and size estimation for crack.

2.2 Computer Simulations

Fig. 2 is the numerical model for a 2-dimensional FEM simulation which contains two anomalies and several cracks. In table 1, the electromagnetic properties are listed. We injected the current with various patterns and then measured the voltages at the same boundary electrodes. After then, we reconstructed the impedance images at multi-frequencies. Fig. 3 shows the imaginary images of reconstructed frequency difference impedance. In Fig. 3, each first column and row mean the frequency used for difference image. We can see two circles and something placed in right side in the second column and the third row in fig. 3.

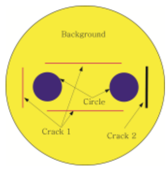


Fig. 2 Simulation model

Table1. model parameter

Anomaly	Impedance
Background	$1+i\omega 10^{-4}$
Circle	$10^{2}+i\omega 10$
Crack 1	$10^{-5}+i\omega 10^{-7}$
Crack 2	$10^{-5}+i\omega 10^{-7}$
Anomaly	**thickness**
Crack 1	10^{-4}
Crack 2	10^{-2}

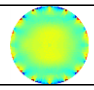
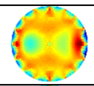
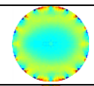
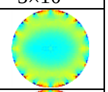
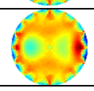
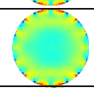
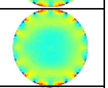
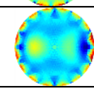
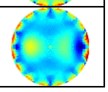
Hz	10	10^4	5×10^7	5×10^8
1				
10				
10^4				

Fig. 3 Frequency difference impedance images

2.3 Phantom Experiments

In order to obtain multi-frequency impedance images, we developed the 16-channel mfEIT system based on an impedance measurement module (IMM). This system is descended from KHU Mark2 EIT system used in biomedical engineering [11]. It is operated from 50 Hz to 500 kHz with maximum data acquisition speed of 100 scans/s. We can increase the amount of input current to improve the sensitivity. However, it causes the high dynamic input range considered by the high impedance imaging object and relatively high injecting current. An IMM consists of an independent current source, an independent differential voltmeter, and a current source calibrator which allows automatic self-calibration of the current source. IMM based mfEIT system can be easily extended to the high number of measurement system. Basic performance factors were assessed with resistor phantom.

The signal to noise ratio was over the 80dB. We did numerical simulations with different shape of cracks and rebar at multiple frequencies. Using the impedance spectrum information, we can easily distinguish the material properties and shape difference. We evaluated the system using a circular shaped phantom with some anomalies like a crack. Fig. 4(a) shows two phantoms with some anomalies, and fig. 4(b) and (c) are the images of reconstructed frequency difference impedance. We can easily see the difference between (b) and (c) in the same row which means that the electrical impedance would be changed as electrical frequency changed. This result can provide the feasibility to improve the assessment of crack identification with multiple objects even though it has a poor spatial resolution.

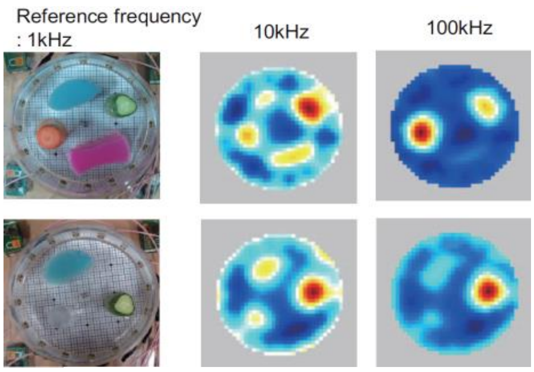


Fig 4. Phantoms with some anomalies (a), the frequency difference of 10kHz (b) and 100kHz (c) images

3. Conclusions

In this paper, we can see any feasibility of mfEIT application for non-destructive detection from computer simulation and phantom experiments. The mfEIT system has strong point in handling, cost and speed however, the image of spatial resolution is low. Therefore, it might be valuable to monitor real-time for any variation in electrical property resulted from a crack inside pipe, system case and structure even during an operation. Especially, if we want just simple information without imaging whether any crack is generated or not, this system could be very far simplified.

For time being, we are going to do further experiments with real subject such as the aged concrete structure, pipe system with a crack, something like that. This method might be useful for safety assessment efficiently.

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