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A DUAL MODALITY COPLANAR ELECTROMAGNETIC SENSOR FOR NON-DESTRUCTIVE EVALUATION APPLICATION

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ABSTRACT

In the field of electromagnetic nondestructive testing, inductive (eddy current) imaging technique is used for the inspection of metallic conductors, while capacitive imaging technique is used on non-conductors. This paper proposed a novel capacitive/inductive dual modality sensor, which can detect defects both in insulation materials and on conducting surfaces. The information of defects on the conducting surface and in the non-conducting layer of the tested specimen can be obtained simultaneously by the proposed sensor with its mode controlled by electronic switches. Finite Element models constructed in COMSOL were used to obtain point spread functions of the sensor in both capacitive and inductive modes.

In this paper, the capacitance/inductive imaging experiments were carried out on a fibre glass-aluminium hybrid structure contains various defects. The defect shape can be detected by real-time imaging, and the defects on the conducting surface and in the non-conductor layer can be distinguished by data analysis of the experimental results.

Keywords: dual modality imaging, inductive, capacitive

NOMENCLATURE

S_σ Capacitance sensitivity.
$\vec{E}_1$ The electric field with coil 1 being excited.
$\vec{E}_2$ The electric field with coil 2 being excited.
S_μ Eddy current sensitivity.
$\vec{H}_1$ The magnetic field with coil 1 being excited.
$\vec{H}_2$ The magnetic field with coil 2 being excited.

1. INTRODUCTION`

Insulated metallic components are commonly used in oil/gas and petrochemical industries. Various types of defects can be found in such structures, i.e. air void and/or water intrusion in the insulation, and corrosion on the metal surface. Previous work has demonstrated that capacitive imaging technique is feasible to detect various types of defect [1-3] and eddy current testing has been proved useful in theory and practice in detecting conductor defects [4-5], it has been widely used for various detection purposes, such as defect detection, material composition detection [6-7]. However, it is difficult to distinguish defect types if capacitive or inductive imaging technique was used respectively.

This work proposed a planar sensor with two coils etched on a PCB board. The coils can work as driving /sensing coils in the inductive (eddy current) mode, and driving /sensing electrodes in the capacitive mode depending on the wiring schemes. The combination of the two sensors makes it can detect both conductor and non-conductor materials at the same time. The effectiveness of the planar coil eddy current sensor has been demonstrated [8-10]. The advantages of planar coil sensors include it can be a complex structure which can be easily arrayed and flexible, small lift-off, high sensitivity, flexible connection with complex surface, easy to manufacture [13]. In recent years, there is a growing interest in planar coil sensors, including analytical modelling of various designs of planar coil sensors [13-15], and different applications [16- 18]. Those studies were mainly focused on crack/flaw detection or NDT based on parameter estimation directly from measurements. To provide a visual interpretation of the system variables, imaging with planar coil sensor is to be further exploited. It is demonstrated in this paper, capacitive imaging mode can be used as a supplement to eddy current imaging mode to distinguish the defects in the non-conducting layer and on the conducting surface.

2. DUAL MODELITY SENSOR

2.1 Sensor Design

The sensor used in this work is composed of two coplanar square spiral coils printed on a PCB, as shown in Fig. 1. The backside of the PCB is also coated as shielding. The number of turns of each coil is 15, the trace width is 0.2mm, the gap between traces is 0.2mm, and the distance between the centres

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of the coil pair is 11 mm. The PCB substrate is made of 1.6 mm FR4.

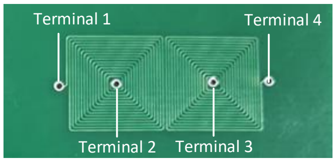


Figure 1: THE DUAL MODALITY SENSOR

The sensor can operate in two modes, namely capacitive imaging and inductive imaging. In the capacitive imaging mode, terminal 1 in Fig. 1 is connected to a driving voltage, terminal 2 and 3 are left empty, and terminal 4 is connected to a charge amplifier that can measure induced charge variation on the sensing coil. In the inductive imaging mode, terminal 1 is connected to the same driving voltage, terminal 2 and 3 are connected to ground, and terminal 4 is connected to a voltage amplifier that can measure the induced voltage across the sensing coil. The connection changes are done by a program controlled switch box.

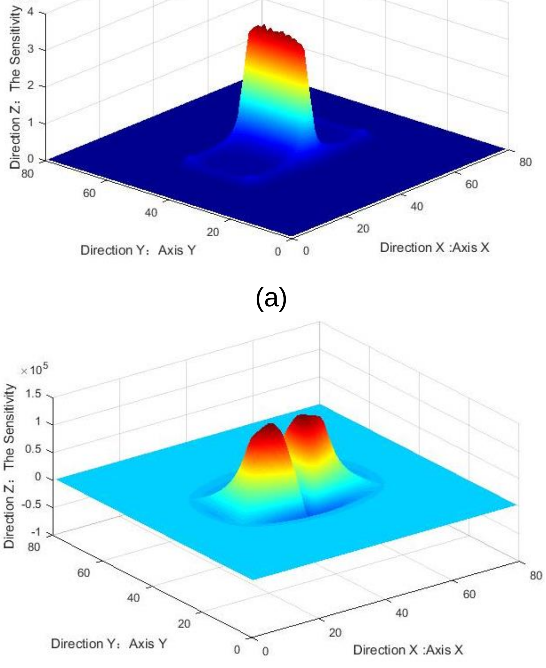
2.2 Sensitivity simulation

The sensitivity formula is derived to predict the imaging performance. The sensitivity formulas of capacitive mode and inductive mode are shown in Eq.(1) and Eq.(2).

$$S_\sigma=\vec{E}_1 \bullet \vec{E}_2 \qquad (1)$$

$$S_\mu=\vec{H}_1 \bullet \vec{H}_2 \qquad (2)$$

According to the Eq. (1) and Eq.(2), COMSOL was used for sensitivity simulation, and the sensitivity at the position of 0.5mm below the sensor was extracted, as shown in Fig.2.



(a)

(b)

Figure 2: THE SENSITIVITY MAPS FOR (a) THE CAPACITIVE MODE AND (b) THE INDUCTIVE MODE

The sensitivity map is the sensor response due to a point perturbation, i.e. point spread function, and can be used to infer imaging performance.

3. RESULTS AND DISCUSSION

A 10 kHz 10V diving voltage from a signal generator is feed in to the sensor via Terminal 1(shown in Fig. 1). Terminal 2 and 3 are connected to ground through two SPST switches. The sensing signal is taken from Terminal 4 and a SPDT switch is used as a 2:1 demultiplex to switch the signal between a charge amplifier (in the capacitive mode) and a voltage amplifier (in the inductive mode). Another SPDT switch is then used to multiplex the pre-amplified signals to a lock-in amplifier. The DC output from the lock-in amplifier is acquired by the NI PXI system. To perform a raster scan, the sensor is held and manipulated by an X-Y scanning stage. At each scanning position, the switches change their states once, and the readings from the capacitive imaging mode and inductive imaging mode are obtained and stored separately. The switch box, the scanning stage and the data acquisition system are controlled by a software developed in LabVIEW. Two images, capacitive image and inductive image, can be formed simultaneously after a step by step scan.

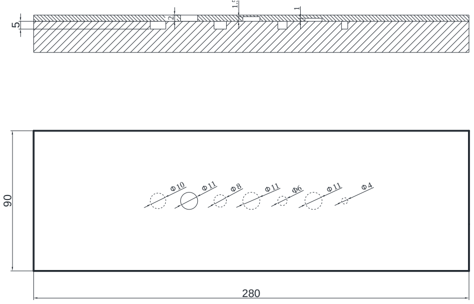
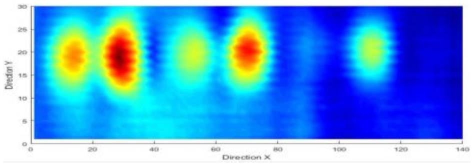


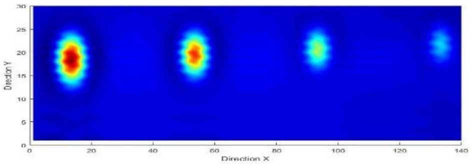
Figure 3： GEOMETRY OF SPECIMEN AND DEFECTS

The first specimen is an aluminium-glass fibre hybrid structure. The 280 mm by 90 mm aluminium plate is with four 5 mm deep flat-bottomed circular holes. The diameters of the holes are 10 mm, 8 mm, 6 mm and 4 mm. A 2 mm thick glass fibre plate with three holes if the same diameter (11 mm) and different depths (2 mm, 1.5 mm and 1 mm) was placed on top of the aluminium plate, and the three shallower holes are hidden if seen from the top, as shown in Fig.3.

The probe shown in Fig. 1 was scanned over a 30 mm by 140 mm at a 0.5 mm lift-off. Two images, namely capacitive image and inductive image, were obtained after a single scan, as shown in Fig.4.



(a)



(b)

- **Figure 4: (a) CAPACITIVE IMAGE AND (b) INDUCTIVE IMAGE FOR THE SPECIMEN SHOW IN FIG. 3**

It can be seen from the capacitive image (Fig.4) all the holes, both on the aluminium plate and in the glass-fibre plate, were detected. This is due to the probing field is sensitive to features in both non-conducting materials and on the conducting surface in the capacitive imaging mode. In the inductive image, only the four holes on the aluminium plate surface were detected and the sizes of holes can be inferred from the indications in the image. It can be inferred that the defect is located on the aluminum plate or the fiberglass plate.

Another two experiments, namely distinguish insulation defect and narrow crack (0.8 mm wide) on steel plate, and detect hidden crack (3 mm from top surface) in aluminium plate, were carried out but not included in the abstract due to length restriction.

4. CONCLUSIONS

In this paper, the capacitive-inductive imaging was carried out on a fibre glass-aluminium hybrid structure with flat holes. By extracting detection information, the defect shape of the sample can be visually detected by real-time imaging. In addition, there are indications of both the holes in the fibre glass plate and on the aluminium plate in the capacitive image, while in the inductive image, only indications for the holes on the aluminium plate appeared. By comparing the two image obtained simultaneously in a single scan, one can distinguished the defect location.

The dual modality imaging sensors can be used to identify defects in the insulation layer and the conducting surface under the insulation, which makes it promising to be used to target the corrosion under insulation problem in practice. In future work, the dual modality sensor will be manufactures as flexible PCBs for complex specimen geometries and its ability to inspect composite materials will be explored.

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