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DISCRIMINATING THE DEFECTS IN THE INSULATION LAYER AND METAL SURFACE USING MULTI-ELECTRODE CAPACITIVE SENSOR

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ABSTRACT

As a novel nondestructive testing technique, capacitive imaging (CI) has been used to detect the defects within the insulation layer and metal surface in an insulated metallic structure, i.e. pipe or vessel. Due to the non-linearity of the probing field, the defects at different depths in the insulation layer are difficult to compare using the conventional CI sensor with a single pair of electrodes. In addition, the conventional CI sensor cannot provide adequate information to discriminate the defects in the insulation layer and metal surface. In order to solve the above mentioned problems, the multi-electrode capacitive sensor is introduced. The multi-electrode capacitive sensor uses multiple quasi-static fringing electric fields generated by an array of coplanar electrodes to obtain extra information about the defects in the specimen. In this work, the Measurement Sensitivity Distributions (MSDs) of the multi-electrode capacitive sensor were acquired using the FEM models, and used as a tool to predict the sensor response due to defect at different depth. Experimental results show that the Dynamic Change Rates (DCRs) of the measured values in insulator layer and metal surface present different variation patterns, which can be used to discriminate these two kinds of defects. In addition, it was demonstrated that the different depths of two defects in the insulation layer can be compared by comprehensive analysis of the detection results from all the electrode pairs.

Keywords: multi-electrode, insulation layer, defect discrimination

1. INTRODUCTION

Insulation layer is a protective structure for metal pipeline to resist corrosion. It is used to insulate metal pipeline from corrosion environment such as moisture content, to restrain the occurrence of corrosion on the surface of metal pipeline and finally to achieve the purpose of controlling corrosion [1]. Due to defects in pipeline production, external mechanical action, disturbance or pressure of soil, wear of rock, bacterial invasion and other factors, the defects both in insulation and metal surface often occur [2, 3]. Discriminating the defects in the insulator layer and metal surface is thus beneficial to take appropriate remedial measures to reduce maintenance cost and improve production efficiency. Many previous works which has been done aim to detect the defects [4-7]. It is a challenging work for conventional NDE technique and capacitive imaging (CI) technique has been proven to be a feasible technique in previous work [8].

It is not possible to compare the defects at the different depths in the insulation layer and discriminate the defects within the insulation layer and metal surface using the conventional CI sensor with a single sensing electrode, because using a single pair of electrodes is hard to obtain more information about the defects without changing the lift-offs. In order to solve the above problems, the multi-electrode capacitive sensor which can give more information about the defects in the depth direction was proposed and introduced in this paper [9].

2. MEASUREMENT SENSITIVITY DISTRIBUTIONS

As shown in Fig.1, a multi-electrode capacitive sensor consists of ten co-planar electrodes, one being the driving electrode (No.1) and the others being the sensing electrodes (No.2-10). The nine pairs of electrodes have different centre separations, which may give more depth information in theory. The multi-electrode capacitive sensor also has a surrounding shielding electrode (No.11) which is used to shield external stray capacitance.

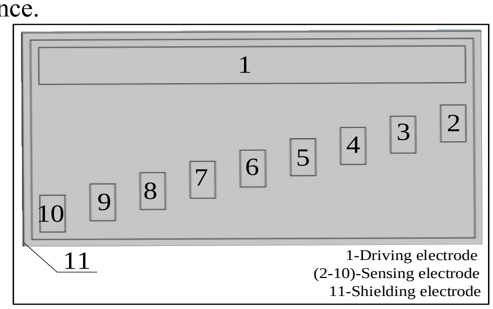

FIGURE 1: THE MULTI-ELECTRODE SENSOR

The MSD, which describes how effectively each region in

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the probing area contributes to the measured charge signal on the sensing electrodes (No.2-10), can be used to comprehensively evaluate the performance of the multi-electrode capacitive sensor. According to Equation (1), the value of MSD at every given position with coordinate (x, y, z) can be calculated.

$$S(x, y, z) = -\vec{\xi}_D \cdot \vec{\xi}_E \qquad (1)$$

Where ξ_D and ξ_E are the electric fields in the position (x, y, z) when the driving and sensing electrodes are energized with excitation voltage of the same size respectively. As the angle between ξ_D and ξ_D can less than, equal to or greater than 90 degrees, the value of MSD which is the negative inner product of these two vector can be positive, zero and negative according to Equation (1).

As shown in Fig.2, the MSD diagrams of the multi-electrode capacitive sensor were obtained by the cross-sections of 3D FEM models. From Fig.2(a) to Fig.2(i), the MSDs of nine pairs of electrodes show different trends. With the increase of the centre distances, the positive MSDs show a trend of increasing first and then decreasing, and the negative MSDs show a decreasing trend all the time. The different trend of positive and negative MSDs can be used to explain the feasibility of discriminating the defects in the insulator layer and metal surface.

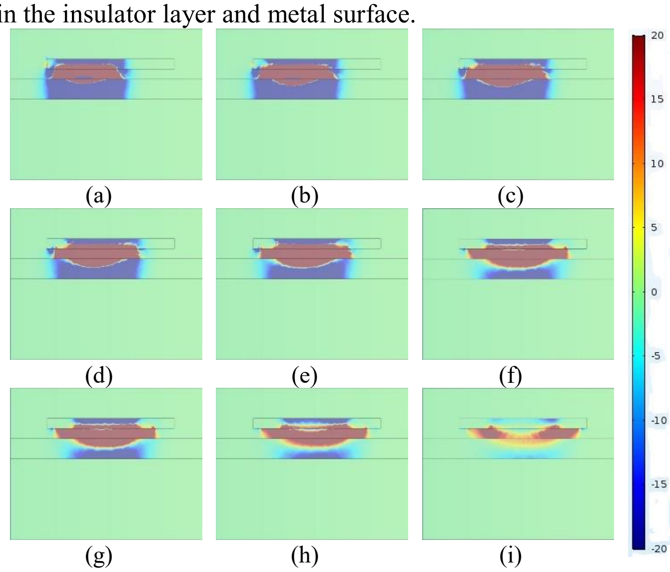

FIGURE 2: MSD DIAGRAMS OF THE MULTI-ELECTRODE SENSOR: C2-1 (a), C3-1 (b), C4-1 (c), C5-1 (d), C6-1 (e), C7-1 (f), C8-1 (g), C9-1 (h) AND C10-1 (i)

3. EXPERIMENTS OF THE MULTI-ELECTRODE CAPACITIVE SENSOR

The multi-electrode capacitive sensor is an important part of a CI system that can be used for detecting the defects, and the setup of our basic experimental system is shown in Fig.3. Besides the multi-electrode capacitive sensor, this CI system consisted of a function generator, a charge amplifier, a lock-in amplifier, a step monitoring controller, an X-Y-Z scanning stage, PXI and software.

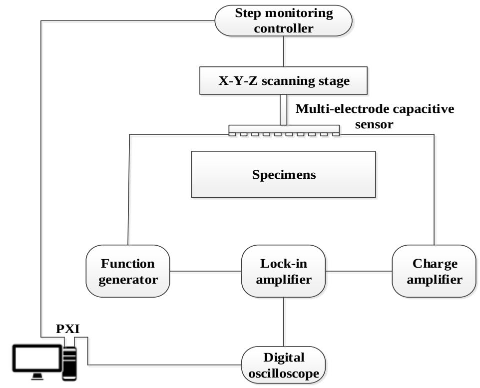

FIGURE 3: SETUP OF BASIC EXPERIMENTAL SYSTEM

The specimen used in this work is a fibreglass-aluminium hybrid structure, as shown in Fig.4, the specimens contain three defects, one being on the metal surface and the others being in the insulator layer.

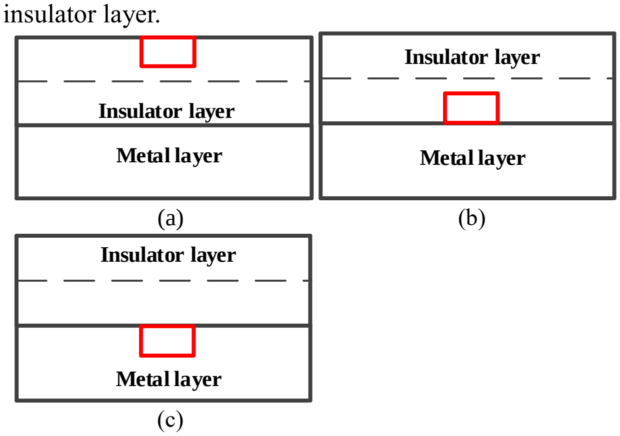

FIGURE 4: THE SPECIMENS CONTAINING THREE DEFECTS WITH DIFFERENT DEPTHS: DEFECT #1 (a), DEFECT #2 (b), DEFECT #3 (c)

The DCR is usually used to evaluate the performance of the conventional CI sensor under the condition of reducing the effect of external noise signals, and it can evaluate the conventional CI sensor with different orders of magnitude on the same benchmark. The DCR can also be used to analyze the performance of the multi-electrode capacitive sensor, and it is defined as follow

$$DCR = \frac{y - yn}{yn} \qquad (2)$$

where, y is the measured value from the multi-electrode capacitive sensor inspecting the specimen which contains defects, and yn is the mean value of the same multi-electrode capacitive sensor inspecting the specimen where there are no defects.

The DCRs of the multi-electrode capacitive sensor detecting three defects are shown in Fig.5. Compared with these three figures, it can be seen that only Fig.5(c) is all above zero. Fig.5(c) is the result of the multi-electrode capacitive sensor detecting the defect in metal surface (defect #3), because the negative MSD near the metal surface causes the opposite trend. Compared with other two figures, the DCRs of C4-1, C5-1 and

C6-1 are below zero in Fig.5(a), and the DCRs of C7-1, C8-1 and C9-1 are below zero in Fig.5(b). The negative MSDs of C4-1, C5-1 and C6-1 are larger than the negative MSDs of C7-1, C8-1 and C9-1 in Fig.2, so it can be sure that Fig.5(a) is the MSDs of detecting defect #1, and Fig.5(b) is the MSDs of detecting defect #2.

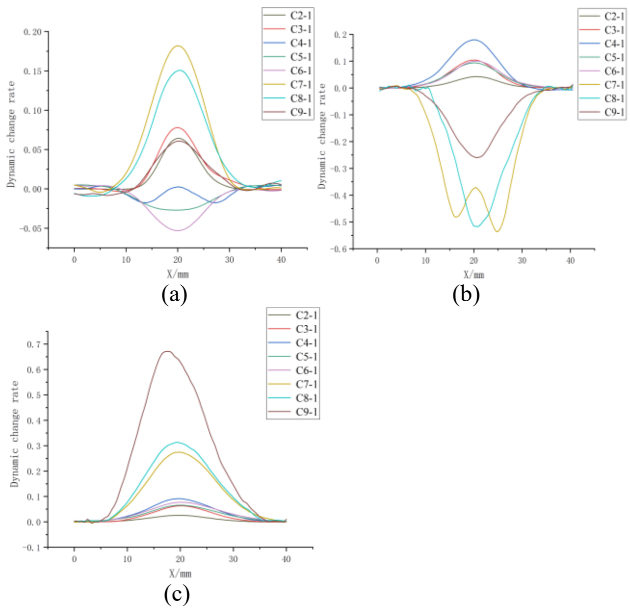

FIGURE 5: THE DYNAMIC CHANGE RATE OF THREE DEFECTS WITH DIFFERENT DEPTHS: DEFECT #1 (a), DEFECT #2 (b), DEFECT #3 (c)

4. CONCLUSIONS

In this paper, a new CI sensor with multiple electrodes was used to discriminate defects in the insulation layer and metal surface. The MSDs of the multi-electrode capacitive sensor detecting the defects were acquired using the FEM models. The DCRs of the measured values obtained at the centre of these two kinds of defects presented different variation patterns. For the defect in the insulator layer, the DCRs of the measured values obtained at the centre of the defect might be positive, zero and negative. While for the defect in the metal surface, the DCRs of the measured values obtained at the centre of the defect were all above zero. These different variation patterns could be used to discriminate defects in the insulation layer and metal surface. Comparing these three figures, it can be found that Fig.5(a) is the MSDs of detecting defect #1, Fig.5(b) is the MSDs of detecting defect #2, and Fig.5(c) is the MSDs of detecting defect #3.

In future, the change rules of MSDs and DCRs of detecting the defects in the insulation layer and metal surface using the multi-electrode capacitive sensor will be further studied when the lift-off changes and the influence of different regions of the negative MSDs on detection results will be further analyzed.

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