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ELECTRICAL POTENTIAL AND ELECTRICAL FIELD DISTRIBUTION OF SQUARE ELECTRICAL CAPACITANCE TOMOGRAPHY

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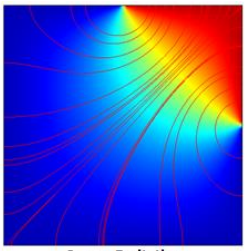
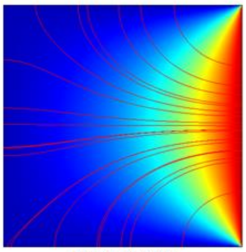
Graphical abstract


Corner Excitation


Side Excitation

Abstract

Electrical Capacitance Tomography (ECT) system helps user to understand the flow distribution inside the close pipe by detecting the variation of permittivity distribution in the inspection area. Generally, most reported ECT systems are implemented to circular shape pipe only. However, square shape pipes are sometimes found in power industry and chemical reactor, therefore this paper is studying the electrical distribution of ECT system within a square pipe. ECT is able to provide fast response, low cost and non-radiation system but similar to all other electrical tomography system, ECT suffers from soft-field effect. This paper proposes segmentation excitation to overcome this problem. Segmentation excitation applies when more than one electrode excited at one time. This paper focuses Protocol 2 or 2-electrode excitation for 8-electrode square ECT system. The simulation was done by using COMSOL Multiphysics. The images of the excitations are presented in this paper. The electrical potential is recorded at the center of the system to analyses the strength of the electrical potential. In addition for square ECT system, the corner configuration provides 3.40% higher electrical potential compared to side excitation configuration.

Keywords: Electrical Capacitance Tomography, segmentation excitation

1.0 INTRODUCTION

Electrical Capacitance Tomography applies by detecting the variation of permittivity between two plates [1]. The array of plates or sensors is fabricated at the outer walls [2]. The permittivity variation will produce different electrical potential, which is projected as images. The images are used as the monitoring tool for ECT to inspect closed region area such as pipes and vessel. There are three main components of ECT; the sensors, data acquisition system (DAQ) and the graphic display unit. The DAQ processes all the data transferred from the sensors arrays to be displayed on the graphic display unit [3].

The driven adapting ECT in industrial application is the progression needs for monitoring, to fulfill requirement for quality control inspection. During this development, the use of ECT measurement technique has become increasingly popular. Manufacturing process monitoring is essential for industrial application to ensure the process performance is within the limits. ECT is not only used in the oil and gas industries but also food and beverage industries, biochemical, mining and even process insulation applications [4]. Comparing with other tomography modality, ECT remains prominent as it able to produce fast response, robustness, affordable construction and fabrication cost, non-radiation tool, and suitability for small or large vessels [1, 5].

Most of the reported works of ECT involves circular shape pipe or vessel [6]. However, there are some studies conducted for different shape of vessel based on application requirement such as power industry [7] and chemical reactor [8]. For example, square shape pipe is used in fluidized bed to understand the bubble behavior and distribution at the bottom zone [9]. In this paper, the simulation of an 8-electrode ECT is presented to show the electrical potential and electrical field distribution using COMSOL Multiphysics for non-conventional pipe.

As a soft-field sensor, ECT provides low resolution images especially towards the center of the pipe [10]. Soft-field sensor is related to the inhomogeneous sensitivity distribution inside the inspection area [11] which is different from hard-field sensor. The generation of electrical field of soft-field sensors is depending on the location sensor arrays. Thus, the electrical field gradually becomes poorer towards the center of the pipe. There are several approaches to overcome the low resolution images problem which includes the study of size of electrode [12], dual modality tomography [13, 14], and controlling the excitation method of the electrodes[15, 16]. This method offers the least modification of the hardware as it involves the modification of the electrical switching [17].

This paper discusses the segmentation excitation method which involves more than one electrode excited at one time. Segmented excitation also relates to the ECT protocol; the number of the protocol depends on the number of electrode excitations at the same time. For example, single excitation is also known as Protocol 1, where just one electrode is excited. The independent measurement (M) is calculated using Equation (1):

$$M = \frac{N(N-1)}{2} \quad (1)$$

Protocol 2 is also known as pair excitation; whereby there two electrodes excited at the same time. Protocol 3 applies three electrodes are excited at the same time. The independent measurement (M) for Protocol 2 and 3 can be calculated using equation (2);

$$M = \frac{N(N-(2P-1))}{2} \quad (2)$$

where P is the protocol number, which can be presented as the number of electrodes grouped together to be excited at the same time, and N is the number of electrode in the ECT system.

There are many studies conducted regarding segmentation excitation which is able to increase the image scanning speed [18] and provide more information about the material distribution [19], and produces less sensitive to noise ratio [20].

2.0 EXPERIMENTAL

This research involves a simulation study 8-electrode ECT system. Adopted a case study conducted by Peng et. al [12]which indicates that the optimal length of the electrode is the same as the width of the pipe. Thus, for this research the number of electrode excited at the same time is two electrodes; which is the same width with the length of the pipe. Figure 1 shows the ECT 8-electrode ECT model with 2mm electrode size.

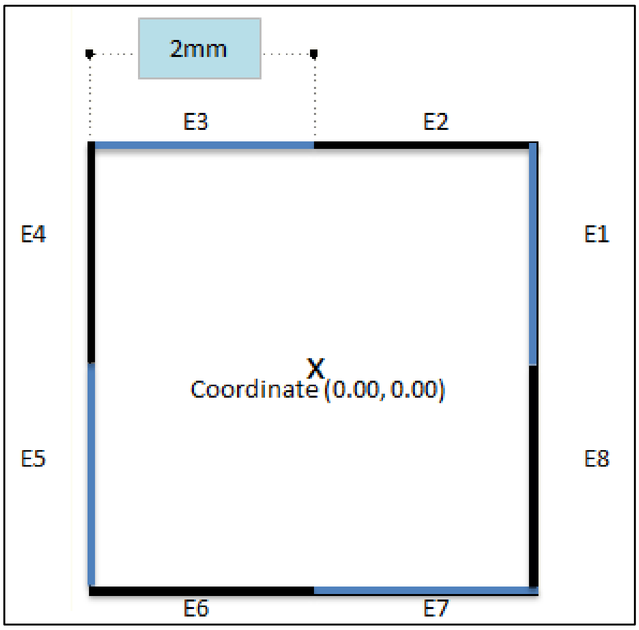


Figure 1 Square ECT Model

From Figure 1, the eight electrodes are indicated with E1 until E8. The ECT model is placed at the center of the pane with intersection is at coordinate (0.00, 0.00). The electrical potential is recoded at the center of the system as it receives the lowest signal due to soft-field effect sensor [21]. Table 1 shows the switching of excitation configuration of the analysis.

Table 1 The segmented excitation configuration

Switching configuration	Excited Electrode
Switching 1	E1 & E2
Switching 2	E1 & E3
Switching 3	E1 & E4
Switching 4	E1 & E5
Switching 5	E1 & E6
Switching 6	E1 & E7
Switching 7	E1 & E8

According to Table 1, there are seven excitation combinations; for 1st switching, electrode 1 (E1) and electrode 2 (E2) are excited. For 2nd switching, electrode 1 (E1) and electrode 3 (E3) are excited. Subsequently, for 3rd switching, Electrode 1 (E1) and Electrode 4 (E4) are excited at the same time. The total length of the excitations is the same; which is 4 mm, but the location of the second electrode is changed. The 1st electrode is fixed at electrode 1 (E1). The feasibility of segmented excitation is tested by changing the position of the ports. The images of electrical fields and electrical potential distribution are recorded and tabled for comparison purposes. In addition, the electrical potential at the center of the model is recorded for each switching.

2.1 ECT Modeling Setup

The 8-electrode ECT is modeled using COMSOL Multiphysics. COMSOL Multiphysics is finite element analysis (FEA) engineering software, which enables user to simulate the experimental setup numerically [22].

The Electrostatic Module in the simulation is selected to model the ECT system to study the electrical potential and electrical field distribution inside the inspection area [22]. The boundary and subdomain conditions are set accordingly to the desired physical analysis and interpretation, [23]. Figure 2 shows the boundary and subdomain setup for the analysis.

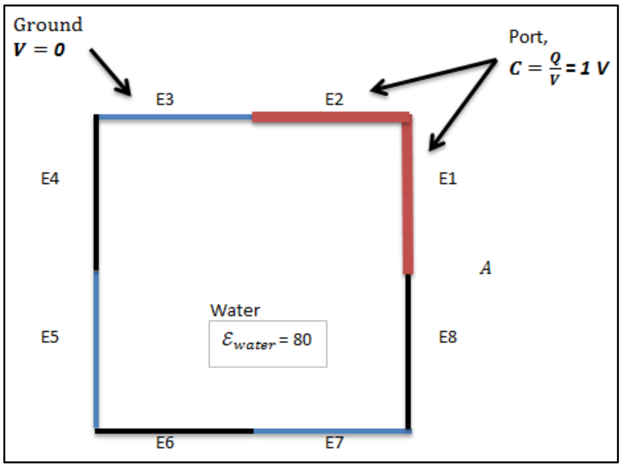


Figure 2 The boundary and subdomain setting

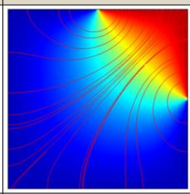
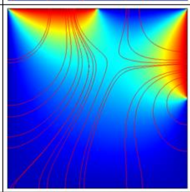
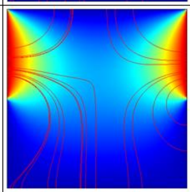
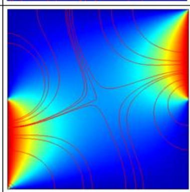
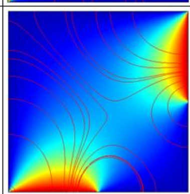
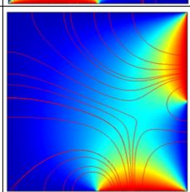
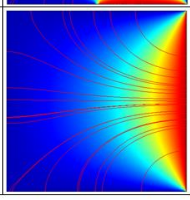
From Figure 2, electrode 1 and 2 (E1 and E2) are set to 1V when these electrodes are used as ports or transmitters. The rest of the electrodes are grounded with V=0. The ECT system is filled with water ($\mathcal{E}_{\text{water}} = 80$). The relation to the excitation methods with the distribution tendency of the electrical potential at the center of the pipe is recorded. The electrical potential distribution and the electrical potential values are recorded and discussed in the next section.

3.0 RESULTS AND DISCUSSION

From calculation single excitation method for 8-electrode ECT system produces 28 independent measurement (M) (refer Equation 1). When 8-electrode ECT system applies Protocol 2 for its excitation, the independent measurement (M) produces is 104 (refer on Equation 2). Greater independent measurement provides better image reconstruction resolution.

The simulated result from COMSOL Multiphysics provides graphical distribution of electrical potential and electrical field. Table 2 shows the distribution of electrical field and potential from the segmentation excitation method. The electrical fields are indicated by red color for the highest potential and blue color for the lowest potential. The red streamlines are the electrical field. The tendencies of the electrical fields are from the ports towards the receivers or detectors. From the figure, switching 1 and 7 shows good coverage based on the streamlines distribution of the electrical field. This means the adjacent pairing is the best combination.

Table 2 The electrical potential distribution for various segmentation excitations

Switching Configuration	Image of switching	Voltage value at the center of the system (V)
Switching 1		0.265
Switching 2		0.264
Switching 3		0.257
Switching 4		0.250
Switching 5		0.248
Switching 6		0.241
Switching 7		0.256

Referring to images in Table 2, the signal for all excitation method managed to reach the center of the ECT system respectfully. The center of the ECT system is the crucial area of the system, thus, it is important that the signal manage to reach the center area of the inspection area. Later, the electrical potential at the center of the pipes are recorded at plotted into a graph for better understanding. Figure 3 shows the tendency of the electrical potential for each switching. The focus of the comparison is switching 1 (E1 and E2) and switching 7 (E1 and E8).

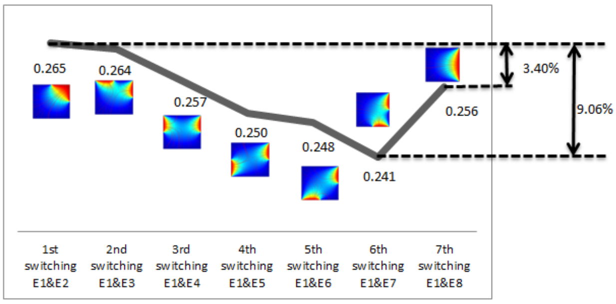


Figure 3 The tendency of electrical potential at the center of the pipe

From Figure 3, the tendency of the electrical potential at the center of the pipe relates with the location of the excitation electrodes. For 1st switching, the electrical potential value recorded at the center of the ECT system is 0.265V. The 2nd switching pairing (E1 & E3) recorded 0.264V. In calculation, 2nd switching contributes 0.50% difference in electrical potential value compared to 1st switching. The 3rd switching stated 0.257V and the difference to 2nd switching is about 2.55%. For 4th switching (E1&E5 pairing), the electrical potential reads at 0.250V at the center of the system. For 5th and 6th switching recorded at 0.248C and 0.241V respectively. The last switching (E1 & E8) stated 0.256V.

From the result, the 1st switching which is the corner configuration indicates the best result of electrical potential value at the center of the pipe. Comparing the adjacent configuration between the 1st and 7th switching contributes about 3.40% in difference in electrical potential value at the center of the ECT system. The 6th switching stated the lowest electrical value which is 0.241V; which is 9.06% difference from the highest pairing (switching 1).

4.0 CONCLUSION

This concludes that although the total area of excitations (ports) is the same, the 2-elecrode with adjacent excitation configuration produces the highest or the strongest potential recorded at the center of the pipe. This can applies for circular pipe ECT system as all sides are in the same angle. In addition, for square ECT system, the corner excitation configuration produces 3.40% better of electrical potential reading compared to side adjacent configurations.

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