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Electric Potential of Various 4-electrode Segmentation Excitation for Electrical Capacitance Tomography System

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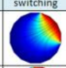
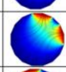
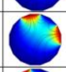
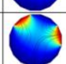
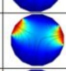
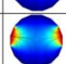
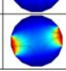
Switching method	Image of switching	Voltage value (V) x10^{-9}
1		1.005
2		0.955
3		0.898
4		0.872
5		0.859
6		0.844
7		0.838

Abstract

Electrical Capacitance Tomography (ECT) system is a non-intrusive method to detect variation of permittivity distribution in a closed pipe. ECT offers fast response, cheap and non-radiation system. However, it suffers from soft-field effect. One of the proposed solutions to overcome this problem is by applying segmentation excitation, which is to have more than one electrode excited at one time. This paper focuses on various segmentation excitations of 4-electrode combinations using COMSOL Multiphysics software. The electrical potential is recorded at the center of the pipe to study the strength of the electrical potential. The result indicates that 4-electrode adjacent configuration recorded 1.005 x 10^{-9}V at the center of the pipe as compared to 0.838 x 10^{-9}V for opposite configuration. This effect shows 16.6% difference in electrical potential at the center of the pipe.

Keywords: Electrical capacitance tomography; segmentation excitation

■1.0 INTRODUCTION

In 1970's, tomography was applied for medical diagnostic imaging [1]. X-ray imaging was developed in 1980's to allow scanning internal structure (bones) of human's body safely and non-invasively. Later, in 1990's tomography has been progressively developed. It was introduced to industrial applications and processes to inspect closed section including food industry, chemical, petrochemical, food and biochemical industries [2]. The development of tomography in industry is driven by the needs and requirement to inspect the process, to adopt resources efficiently, and to fulfill requirement and for inspection of quality control. During this development, the use of Electrical Capacitance Tomography (ECT) measurement technique has become increasingly popular.

Electrical capacitance tomography is a modality to inspect the process flow of a closed region or pipe [3]. The process flow images are captured from an electrode array mounted outside the pipe wall [4]. ECT consists of three main components; the sensors, the data acquisition system and the graphic display unit. The data from the sensor array is transferred to the data acquisition system to be processed and displayed on the graphic display unit [5]. ECT remains popular among other tomographic imaging for its fast response capability, robustness, affordable construction cost, being non-radiation-free , and suitability for small or large vessels [1, 6]. However, ECT produces low resolution images due to its soft-field effect. Soft field effect relates to the sensitivity distribution inside the region of inspection being dependent on the distribution of permittivity within the section. The sensitivity gradually becomes poorer towards the center of the pipe. The main reason because of the soft-field nature of ECT [7] and the generation of the electrical field inside the cross section of the pipe is inhomogeneous [8].

Many studies have been conducted to overcome the low resolution image reconstruction problem within a closed pipeline. Mechanically, the sensor can be rotated to capture all measurements and combine the images, but the mechanical rotation has its limitations, which include control of the fast speed rotation movement. This method is not physically practical physically [9]. Another option is by controlling the excitation method of the electrodes[10]. This method is more relevant, applicable and offers minimum modification of the ECT system hardware. Segmentation excitation is proposed to overcome the problem; by applying more than one electrode excitation at one time. Segmentation excitation is also known as Protocol. In ECT, the number of the protocol depends on the number of electrode excitations at the same time. For example, Protocol 1 is also known as single excitation, 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 and Protocol 3 are applied when two and 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.

Studies show that segmented excitation is able to increase the image scanning speed [11] and provide more information about the material distribution [12]. The segmentation excitation is also able to produce more independent measurements, improved ill-posed problem, improved image reconstruction, and enhanced the uniformity of sensitivity compared to single excitation method [13]. Olmos *et al.* [14] reported the comparison between a single excitation and a segmented 4-electrode ECT system. The experiment was conducted using a 12-electrode ECT system, and the results showed that a segmented reconstructed image produced lower error and less sensitive to noise compared to the single excitation method.

This paper conducts the simulation test using 16-ECT system, and excites 4-electrode at the same time, adopting the test conducted by Olmos *et al.* [14]. From the article, the simulation was done with 4 adjacent excitations (electrode 1to 3, electrode 5 to 6, electrode 7-9 and electrode 10-12). In this analysis, seven different excitation configurations are studied. The electrical potential is recorded at the center of the pipe for comparison for all excitations.

■2.0 EXPERIMENTAL

The feasibility of segmented excitation is tested by changing the position of the ports. The number of excited electrodes is constant for all excitations; where 4 electrodes are excited simultaneously. The modeling is done by using a finite element analysis (FEA), solver and simulation software; COMSOL Multiphysics. The software is used for different physics and engineering applications. COMSOL Multiphysics allows additional equations to represent different condition. This ECT is modeled based on the real system [15] in the lab with 16-electrode at the circumference of the pipe.

2.1 ECT Modeling Setup

The modeling of 2D 16-ECT systems starts with the selection of the module. The Electrostatic Module is selected based on the capability to produce the electrical potential and field within the range of tested area [16]. The geometry of the 16-ECT is modeled. Figure 1 shows the modeling of the 16-electrode ECT system with its respective electrode positioning.

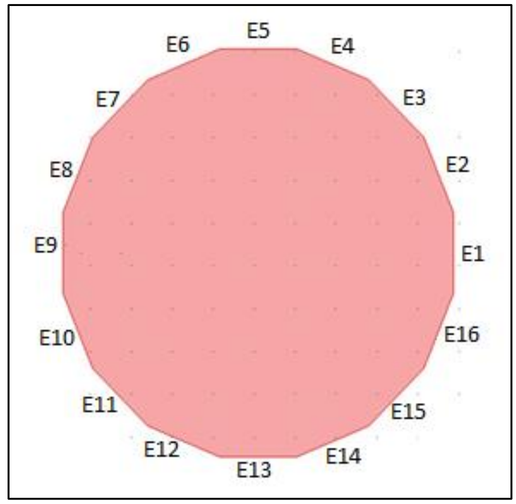


Figure 1 The modeling of 2D 16-ECT

From Figure 1, the labels E1 to E16 represent the location of the sensors at the periphery of the pipe. To explain the physical analysis and interpretation, the boundary and sub domain is applied to the system [17]. Figure 2 shows boundary and sub-domain parameter settings of the system.

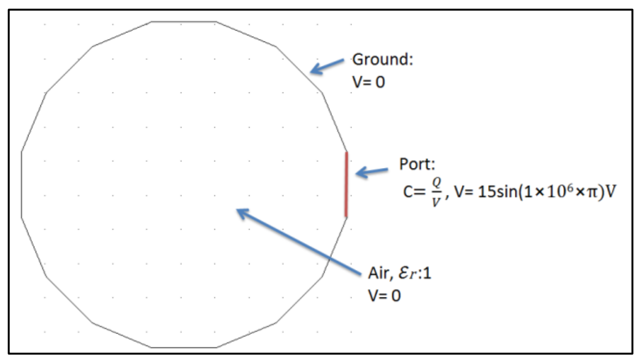


Figure 2 The boundary and sub-domain setting

Figure 2 shows two types of boundary condition of port and ground for the model. Port represents the excited electrode with the potential value of V=15 sin (1 × 106 × π)V. The detector of the ECT system is set as ground with a setting of V=0. The pipe is filled with air with dielectric constant of E_r=1.

2.2 4-electrode Segmentation Excitation

In this paper, the feasibility of segmented excitation is tested by changing the position of the ports. The number of excited electrodes is constant for all excitations; with 4 electrodes excited simultaneously. For comparison with other systems, the electrical potential is captured at the centre of the pipe at coordinate (0.00, 0.00) as shown in Figure 3.

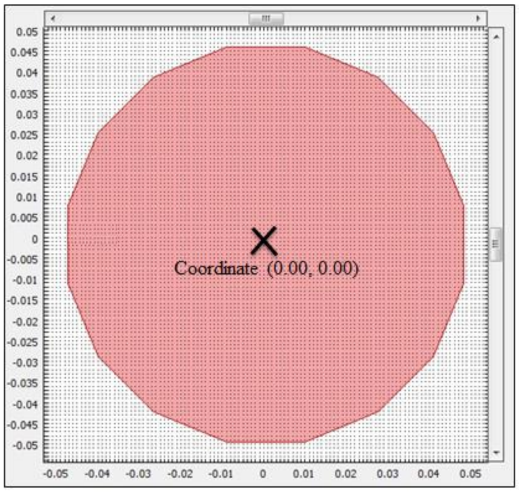


Figure 3 Coordinate (0.00,0.00) of the ECT system

The center of the pipe is targeted to capture the electrical potential as it is the most important point in the pipe which receives the lowest electrical potential from the excited electrode(s) [18]. The configuration of the various 4-electrode are tabled in Table 1.

Table 1 The segmentation configuration

Electrode	Switching method						
	1	2	3	4	5	6	7
E1	1	1	1	1	1	1	1
E2	1	1	1	1	1	1	1
E3	1	0	0	0	0	0	0
E4	1	1	0	0	0	0	0
E5	0	1	1	0	0	0	0
E6	0	0	1	1	0	0	0
E7	0	0	0	1	1	0	0
E8	0	0	0	0	1	1	0
E9	0	0	0	0	0	1	1
E10	0	0	0	0	0	0	1
E11	0	0	0	0	0	0	0
E12	0	0	0	0	0	0	0
E13	0	0	0	0	0	0	0
E14	0	0	0	0	0	0	0
E15	0	0	0	0	0	0	0
E16	0	0	0	0	0	0	0

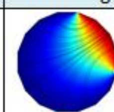
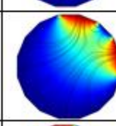
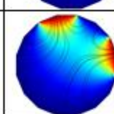
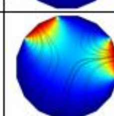
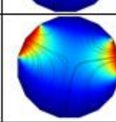
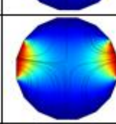
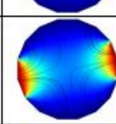
From Table 1, the excited electrodes are represented by “1” while the grounded electrodes are indicated by “0”. There are seven different switching configurations. In the 1st switching method, four electrodes adjacent to one another are excited at the same time. The 2nd switching has 2-pairing electrodes separated by one un-excited electrode. Subsequently, the 3rd switching until the 7th switching configurations separated by two to six un-excited electrodes. 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

For single excitation, the 16-electrode system is equal to 120 independent measurements (refer Equation 1) and 4-electrode segmented excitation contributes to 1824 independent measurement (*M*) (refer Equation 2). This indicates that segmented excitation enables more measurements for the system to increase the image reconstruction resolution.

The results from this analysis are provided based on the graphical distribution of the electrical potential and field. The electrical potential value at the center of the pipe is recorded for all switching configurations. Table 2 indicates the electrical potential or voltage value at the center of the pipe and shows the image reconstruction for each switching.

Table 2 The electrical potential distribution for various segmentation excitations

Switching method	Image of switching	Voltage value (V) x10^{-9}
1		1.005
2		0.955
3		0.898
4		0.872
5		0.859
6		0.844
7		0.838

Referring to the images reconstructed in Table 2, the highest electrical potential is indicated by red color and the blue color represents the lowest electrical potential value in the pipe. From the color distribution, the electrical potential distribution reached the center area for all switching methods. The electrical potentials tendency is studied by plotting the electrical potential value at the center of the pipe. Figure 4 shows the tendency of the electrical potential for every switching in this experiment.

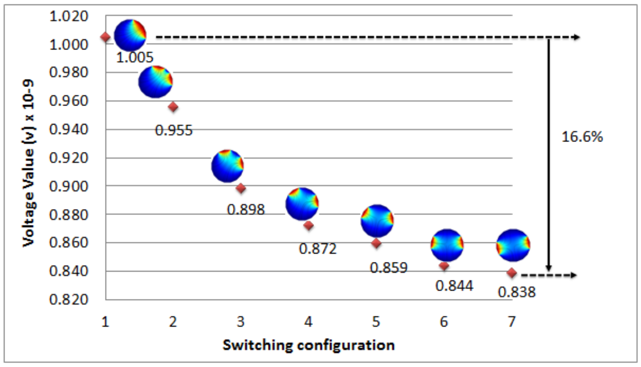


Figure 4 The tendency of electrical potential value at the centre of the pipe for segmentation excitations

From Figure 4, the tendency of the electrical potential at the center of the pipe corresponds with the location of the ports. For all switching methods, the number of electrodes excited at the same time is constant (4 electrodes). For Switching 1, the electrical potential shows the highest value of 1.005×10^{-9}V compared to Switching 7 with 0.838×10^{-9}V of electrical potential value at the center of the pipe. The electrical potential value for Switching 1 is 16.6% higher than Switching 7. This concludes that although the total area of excitations (ports) is the same, the 4-elecrode with adjacent excitation configuration produces the highest or the strongest potential recorded at the center of the pipe.

■4.0 CONCLUSION

From the analysis, the combinations of different configurations of excitation are presented. The number of excited electrode is constant for all excitations, which are 4 electrodes excited simultaneously. The tendency of the electrical potential is observed and plotted onto a graph. The result shows that the adjacent excitation gives 16.6% improvement of electrical potential at the center of the pipe compared to opposite excitation.

Acknowledgement

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