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Electric Potential Distribution of Electrical Capacitance Tomography System at the Centre of Pipe Based on Segmented Excitation

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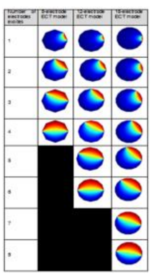
Graphical abstract



Abstract

Electrical capacitance tomography (ECT) is one of the systems used to inspect closed pipe flow. This paper will present the proposed segmented excitation of electrodes with a focus on the low resolution problem. Modelling of 8, 12 and 16 electrodes is done using COMSOL Multiphysics. The number of excitation electrodes is increased until half of the electrodes are excited at the same time. The electrical potential distribution is analyzed and the voltage value at the centre of the pipe is captured. The results show that there is improvement of electrical potential and voltage value in proportion to the number of electrodes excited at the same.

Keywords: Electrical potential; segmented excitations; electrical capacitance tomography

1.0 INTRODUCTION

In the 1980s, tomography techniques were widely used in x-ray medical detection applications [1]. The word 'tomography' is derived from the Greek, where 'tomos' means 'to slice' and 'graph' means 'image' [2]. Nowadays, the functions of tomography have extended to industrial applications including electrical insulation systems, as well as to petroleum industries applications to assist in visualizing conditions within the process pipeline [3, 4]. Electrical capacitance tomography (ECT) is one of the tomography modalities available. ECT describes the characteristics and phases of the flowing components within the closed vessel, by measuring the dielectric properties variation of the material inside the vessel or pipe. Then it reconstructs the cross-sectional images based on the measured capacitance value [5].

The choice of tomographic modalities depends on the purpose of the experiment and the environment of the inspections. Industrial process expectations may differ from medical applications. Low-resolution images may be acceptable in industrial processes. For medical application, the critical requirements are the resolution and the accuracy of the images [6].

The three main components of ECT are the sensors, the data acquisition system and the image reconstruction system [7]. ECT has rapidly developed into one of the most promising tomography applications, as it is non-invasive [8], affordable and simple and has high speed capabilities [9]. However, there are some disadvantages of ECT: it is limited to non-conductive material and produces low resolution images. [10]. The relationship between capacitance and dielectric properties can be given as:

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d_p} \tag{1}$$

where
C = capacitance (F)
ε_0 = permittivity of free space
ε_r = permittivity of the dielectric
A = area of the plate
d_p = the distance between those plates

From the Equation (1) the capacitance increases with the area of the electrodes and decreases when the distance between electrodes increases. Permittivity can be defined as a measurement of response of a substance towards electrical field in a medium. It expresses as the ratio of its electric displacement to the applied field strength. A change of permittivity of the materials flow within the vessel produces different capacitance value inside the pipe.

The significant advantages of electrical capacitance tomography for industrial purposes are to reduce production costs by enhancing efficiencies and yield, to enhance the process efficiency, simplify the process and improve product quality, as a non-intrusive and non-invasive technology system [11]. GTI technologies are embedded in the tomography system to inspect plastic, ceramic and metallic objects to optimise the cost, safety and equipment reliability[12].

With improvement of the fabrication techniques available, the resolution of the tomogram image can also be improved by increasing the number of electrodes installed at the circumference of the pipeline [13]. However, the reconstructed image quality decreases at the centre of the imaging area when the number of electrodes is increased [14]. As the number of electrode increases, each electrode size decreases, resulting in a low signal level being produced by each electrode. Consequently, the imaging area at the centre of the vessel will decrease [15].

To overcome this problem, the number of electrodes that are excited can be increased to cover a larger area of examination. An initial study was conducted by having only one electrode at a time as the transmitter and the remaining electrodes working as receivers [16]. The timing of the detection is shortened when a few groups consisting of one transmitter with several receivers are used within a pipe cross-section [17]. This method produces an increase in the capacitance sensor's flow visualization ability. Olmos *et al*. [13] made a comparison between a single transmitter and a 4-electrode transmitter. The test was done with a 12-electrode ECT system. The result shows better image reconstruction and high values of inter-electrode capacitance. The segmented excitation may help to produce better image reconstruction by supplying higher potential, shorten the scanning step [18], greater independent measurement,[19] and produced lower error and less sensitive to noise [13].

This paper will focus on the detection at the centre of the pipe. If the sensor is located in the wall of the pipe, ECT is insensitive to detect the permittivity changes at the centre of the pipe [20]. Thus, segmented excitation will help detection at the centre of the pipe by supplying higher electrical potential. The experiment will determine the potential value at the centre of the pipe by increasing the number of electrodes that are excited at one time.

■2.0 EXPERIMENTAL SET-UP

2.1 Segmented Excitation

Protocol 1 of ECT is when only one electrode is excited at a time, which can be called single excitation. Segmented excitation differs from protocol 1 of ECT [21]. Protocols 2 and 3 are applied when the electrodes are excited in pairs and the inter-electrode capacitance is determined by various combinations of the receiver's electrodes. Fan beam projection is applied in this simulation test. The transmitter will communicate with detectors along the pipe to detect the different permittivities inside the inspected pipe. The measurement M is given as:

$$M = \frac{E(E-(2P-1))}{2} \qquad (2)$$

Where;
E = number of electrodes
P = protocol or the number of electrodes excited at one time.

Segmented excitation will produce greater independent measurement, enables to increase the process speed [22], more information obtained about the material distribution inside the region of interest [18] and the most importantly, produced better image reconstruction [13].

2.2 ECT Modelling

An ECT system with 8-, 12- and 16-electrode configurations was modelled using COMSOL Multiphysics to study the potential distribution of the electrodes through the cross-section of the pipeline. COMSOL Multiphysics is an engineering software which enables the user to determine the boundary setting and conditions. Various segmented excitation configurations and the distribution of electrical field and electrical potential inside the pipe were simulated and studied. The ECT model can be divided according to the following approach:

a) Choosing the mode in the electrostatics module
b) Geometry modelling according to the dimension to be simulated
c) Generating the mesh
d) Setting electrical properties in the domains
e) Setting the boundary conditions

The boundary conditions used are ground and port capacitance. The equations used for the boundary and subdomain conditions are as follows:

$$v = 0, for\ ground \qquad (3)$$

$$C = \frac{Q}{V}, \text{ for port (excitation electrode} \qquad (4)$$

Where;
C = capacitance value
Q = charge of the two conductors
V = voltage difference between the two conductors

The capacitance is directly corresponding to the surface range of the conductor plates and inversely proportional to the separation between the plates which implies the charges (*Q*) on the plates are corresponding with capacitance while the voltage (*V*) between the plates.

Table 1 shows the length of the ECT model with 8, 12 and 16 electrodes. The ECT model is based on a 110 mm diameter pipeline. Based on the diameter of the studied pipe, the 8-electrode ECT has eight 42 mm electrodes, while the 12-electrode and 16-electrode versions have electrodes with 29 mm and 19 mm electrode lengths respectively. The length of the excitation was represented by the length of the electrode times the number of electrodes excited, as stated in Table 2. The length of each switching is the multiply of the number of electrode excited with the length of the electrode size.

Table 1 Length of electrodes in the ECT model

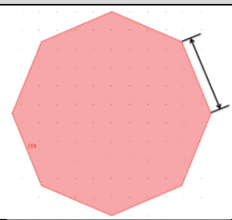
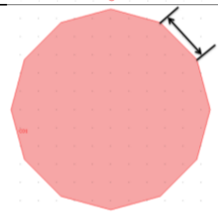
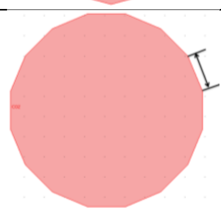
ECT System model		Dimension of the Electrode (m)
8-electrode		0.042
12-electrode		0.029
16-electrode		0.019

Table 2 Lengths of excited electrodes

Number of electrodes excited	Lengths of excited electrodes (m)		
	8-electrode	12-electrode	16-electrode
1	0.042	0.029	0.019
2	0.084	0.057	0.038
3	0.126	0.086	0.057
4	0.168	0.114	0.076
5		0.143	0.095
6		0.171	0.114
7			0.133
8			0.152

The purpose of the simulation is to obtain the voltage value at the centre of the pipe. The central area of the vessel is the crucial area that needs to be inspected due to the low resolution sensitivity and soft-field nature of ECT [23]. For this simulation, uniform permittivity is applied where the material inside the pipe is filled with air.

3.0 RESULTS AND DISCUSSION

Figure 1 shows the image of each switching for the experiment.

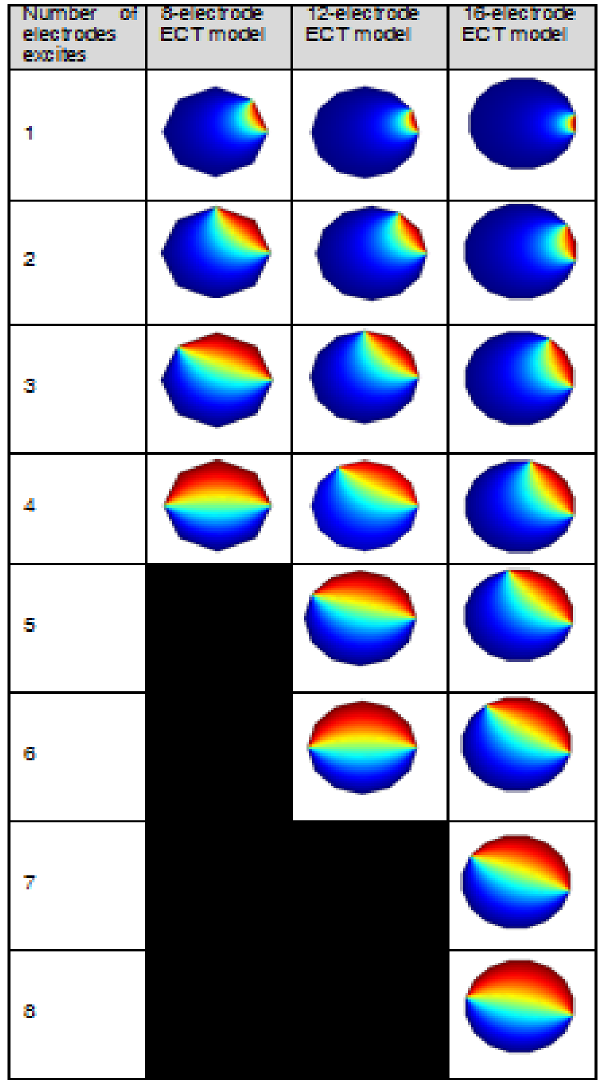


Figure 1 Simulation of ECT model with different numbers of excitation electrodes

Figure 1 shows the simulation results of 8-, 12- and 16-electrode ECT. The blue colour represents the lowest voltage and the red surface indicates the maximum voltage. For single excitation using 12- and 16- electrode ECT, the electrical potential at the centre of the pipe can be considered as the lowest value. For 8-electrode single excitation, the electrical potential is slightly better because the length of the electrode is longer than for the12- and 16-electrode models. As the amount of excitation increases, the electrical potential for all the models shows significant improvement at the centre of the pipe because of the increasing electrical potential supplied and the increase of the detection signal [24] [13], which may thus enhance the image reconstruction.

Table 3 The voltage value at the centre of the pipe

Number of electrodes excited	Voltage at centre of the pipe (V) x 10^{-9}		
	8-electrode	12-electrode	16-electrode
1	0.38	0.27	0.21
2	0.73	0.54	0.42
3	1.14	0.87	0.62
4	1.59	1.49	0.85
5		1.72	1.12
6		1.75	1.29
7			1.48
8			1.94

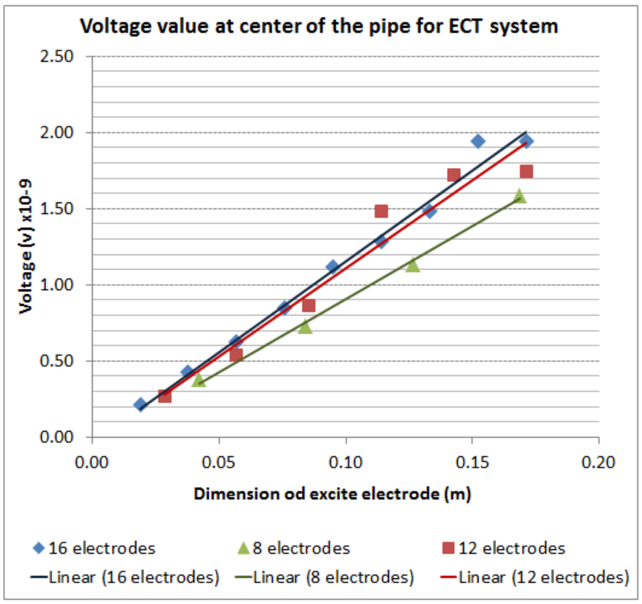


Figure 2 Voltage value at the centre of the pipe vs. the length of the excited electrode

Table 3 indicates the voltage value at the centre of the pipe. As the number of excited electrodes progresses, so does the voltage value. From the simulation result, the voltage at the centre of the pipe is captured and plotted in

Figure 2, showing the tendency of the voltage value at the centre of the pipe as the number of electrodes excited at the same time is increased. The same voltage is given for each electrode, at 15*sin(1000e3*pi) volt. The value given is based on the voltage supply for the existing ECT system.

4.0 CONCLUSIONS

The voltage at the centre of the pipe is proportionate to the number of electrodes excited at the same time. As it is crucial for the centre of the pipe to be inspected for industrial applications, segmented excitation is one solution to obtain a better image at the centre of the pipe. The higher voltage at the centre of the pipe represents better inspection quality and may produce better image reconstruction at the centre of the pipe.

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References

[1] S. Medical. Computed Tomography Its History and Technology. Ed. Germany: Siemens AG, Medical Solutions.

[2] S. S. Donthi and L. R. Subramanyan. 2004. Capacitance based Tomography for Industrial Applications. EE Dept. IIT Bombay.

[3] L. F. M. Moura, E. Cenedese, and A. C. A. Filho. 2009. Numerical Study of a Capacitive Tomography System for Multiphase Flow. *Engenharia Térmica (Thermal Engineering)*. 8: 67–78.

[4] T. Dyakowski, L. F. C. Jeanmeure, and A. J. Jaworski. Applications of Electrical Tomography for Gas–Solids and Liquid–Solids Flows—A Review. *Powder Technology*. 112: 174–192, 10/31/ 2000.

[5] Y. Hua, L. Chunting, and G. Jing. 2004. Electrical Capacitance Tomography Image Reconstruction Based on Singular Value Decomposition. In *Intelligent Control and Automation, 2004. WCICA 2004. Fifth World Congress on*. 4: 3783–376a.

[6] K. J. Alme and S. Mylvaganam. 2007. Comparison of Different Measurement Protocols in Electrical Capacitance Tomography Using Simulations. *IEEE Transactions On Instrumentation And Measurement*. 56: 2119–2130.

[7] R. A. Rahim. 2011. *Optical Tomography Principles, Techniques, and Applications*. Johor Bahru: Penerbit UTM.

[8] Norberto, Flores, J. C. Gamio, C. Ortiz-Alemán, and E. Damián. 2005. Sensor Modeling for an Electrical Capacitance Tomography System Applied to Oil Industry. *Excerpt from the Proceedings of the COMSOL Multiphysics User's Conference 2005 Boston*.

[9] E. J. Mohamad, R. A. Rahim, L. Leow Pei, M. H. F. Rahiman, O. M. Faizan Bin Marwah, and N. M. N. Ayob. 2012. Segmented Capacitance Tomography Electrodes: A Design and Experimental Verifications. *Sensors Journal, IEEE*. 12: 1589–1598.

[10] J. Lei, S. Liu, Z. H. Li, and M. Sun. 2008. Image Reconstruction Algorithm Based On The Extended Regularised Total Least Squares Method For Electrical Capacitance Tomography. *Science, Measurement & Technology, IET*. 2: 326–336.

[11] Q. Marashdeh, W. Warsito, L.-S. Fan, and F. L. Teixeira. 2006. A Nonlinear Image Reconstruction Technique For ECT Using A Combined Neural Network Approach. *Measurement Science and Technology*. 17: 2097–2210.

[12] B. J. Huber. 2003. Capacitive Tomography for the Location of Plastic Pipe. NETL AAD Document Control Bldg. 921.

[13] A. M. Olmos, M. A. Carvajal, D. P. Morales, A. García, and A. J. Palma, 2008. Development of an Electrical Capacitance Tomography System using Four Rotating Electrodes. *Sensors and Actuators A: Physical*. 148: 366–375.

[14] E. Johana, F. R. M. Yunus, R. A. Rahim, and C. K. Seong. 2011. Hardware Development od Electrical Capacitance Tomography for Imaging a Misture of Water and Oil. *Jurnal Teknologi*. 54: 425–442.

[15] C. G. X. i. e, S. M. Huang, C. P. Lenn, A. L. Stott, and M. S. Beck. 1994. Experimental Evaluation of Capacitance Tomographic Flow Imaging Systems Using Physical Models. *IEE Proc.-Cbcuits Devices System*. 141: 357–368.

[16] L. Thomas, W. Radoslaw, and M. Dieter. 2001. Electrical Capacitance Tomography: Image Reconstruction Along Electrical Field Lines. *Measurement Science and Technology*. 12: 1083.

[17] R. A. Rahim, L. L. Chen, C. K. San, M. H. F. Rahiman, and P. J. Fea. 2009. Multiple Fan-Beam Optical Tomography: Modelling Techniques. *Sensors 2009*. 9: 8562–8578.

[18] K.-J. J. Alme and S. Mylvaganam. 2007. Comparison of Different Measurement Protocols in Electrical Capacitance Tomography Using Simulations. *IEEE Transactions on Instrumentation and Measurement*. 56: 2119–2130.

[19] L. Lanying, G. Ming, and C. Deyun. 2011. A Novel Multiple-Electrodes Excitation Method For Electrical Capacitance Tomography System. In *2011 6th International Forum on Strategic Technology (IFOST)*. 1167–1171.

[20] W. Q. Yang. 1996.Calibration of Capacitance Tomography Systems: A New Method for Setting System Measurement Range. *Measurement Science and Technology*. 7: L863.

[21] P. T. LTD. 2009. Process Tomography Ltd. Electrical Capacitance Tomography System Type Tflr5000 Operating Manual - Fundamentals Of ECT. Wilmslow UK.

[22] Z. Fan and R. X. Gao. 2011. Enhancement of Measurement Efficiency for Electrical Capacitance Tomography. *IEEE Transactions on Instrumentation and Measurement.* 60: 1699–1708.

[23] C. G. Xie, S. M. Huang, B. S. Hoyle, R. Thorn, C. Lenn, D. Snowden*, et al.* 1992. Electrical Capacitance Tomography For Flow Imaging: System Model for Development of Image Reconstruction Algorithms and Design of Primary Sensors. *Circuits, Devices and Systems, IEE Proceedings G*. 139: 89–98.

[24] E. J. Mohamad, R. A. Rahim, P. L. Leow, M. H. Fazalul Rahiman, O. M. F. Marwah, N. M. Nor Ayob, *et al.* 2012. An Introduction of Two Differential Excitation Potentials Technique In Electrical Capacitance Tomography. *Sensors and Actuators A: Physical*. 180: 1–10.