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FINITE ELEMENT ANALYSIS ON ELECTRICAL CAPACITANCE SENSOR GUARD

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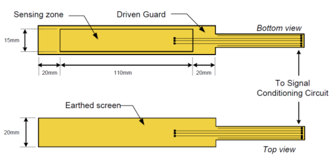
Graphical abstract



Abstract

Electrical Capacitance Tomography (ECT) is widely used for multiphase flow measuring and monitoring purposes. In this paper, a customized sensor electrode is introduced for ECT system. This sensor has an embedded guard using flexible FR4 copper plate which makes it advantage over the conventional type of design in terms of smaller in size, easy to attach on pipe circumference and has lower noise. To investigate the behaviour of the sensor guard, a Finite Element Method (FEM) using COMSOL Multiphysics software comes necessary. An emulated experiment is carried out to solve the sophisticated numerical studies to model the customized ECT sensor and its embedded noise guards.

Keywords: Tomography, electrical capacitance, comsol, finite element analysis, sensor guard

Abstrak

Tomografi Kemuatan Elektrik (ECT) digunakan secara meluas untuk mengukur dan memantau pengaliran cecair campuran. Dalam kertas ini, penderia elektrod kapasitan telah diperkenalkan untuk sistem ECT. Penderia ini mempunyai pengawal penghapusan derau yang dibuat dari bahan tembaga FR4. Kelebihan penderia ini lebih berbanding rekabentuk penderia konvensional adalah dari segi saiz yang lebih kecil dan kebolehannya untuk dilenturkan dan dilampirkan diatas lilitan permukaan paip. Untuk mengkaji fungsi dan keberkesanan penderia ini, Kaedah analisis elemen terbatas (FEM) menggunakan perisian COMSOL Multiphysics adalah diperlukan. Satu ujikaji telah dijalankan untuk menyelesaikan pengiraan model matematik ECT bersama pengawal penghapusan derau.

Kata kunci: Tomografi , Kemuatan elektrik, comsol, analisis elemen terbatas, penderia pengawal penghapusan derau

1.0 INTRODUCTION

Electrical Capacitance Tomography (ECT) has been extensively employed in the field of flow measurement and monitoring applications such as food and beverage industries, oil and gas industries and others. ECT systems consist of several electrode sensors located on a pipe circumference to obtain information about the distribution of the region of interest. A basic block diagram of such system is illustrated in Figure 1 [1].

The principle of ECT sensor is to measure capacitance from dielectric components which can be determined by Equation 1:

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

where C is the capacitance value, ε_0 is the permittivity value in free space, ε_r is the permittivity value of the dielectric material, *A* is the sensing zone and d_p is the distance between electrode sensors.

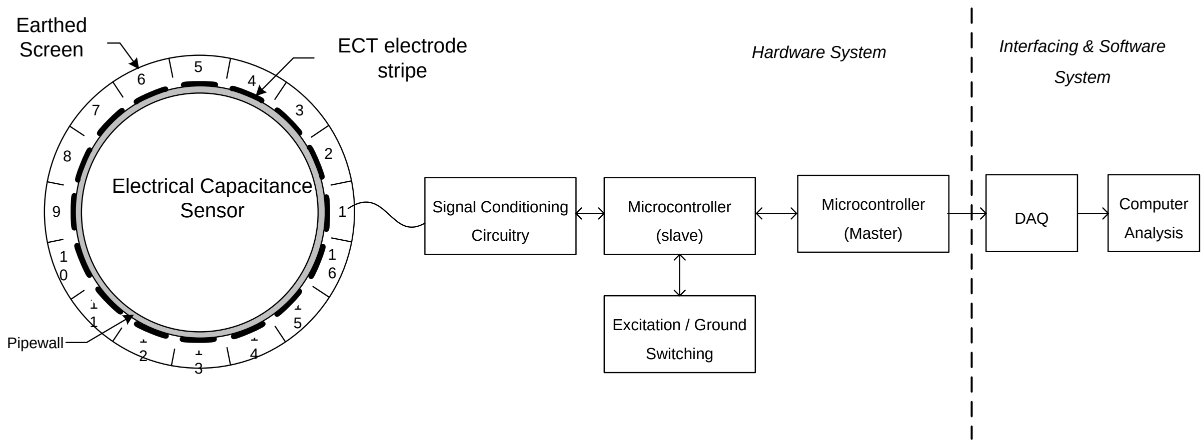


Figure 1 Electrical capacitance tomography system

2.0 SENSOR CONFIGURATION

A typical electrical capacitance sensor considered applying earthed screens and sensor guards as illustrated in Figure 2.

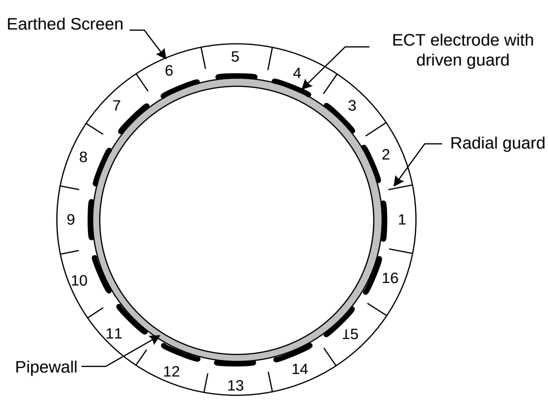


Figure 2 Cross-sectional view of ECT sensor design with guards

From Figure 2, sensor material selection should be from the highly conductive type to detect changes of permittivity in dielectric materials. This conventional design uses earthed screen at the outer layer to prevent interference of external noise while radial guards located between adjacent electrodes to prevent fringe-effect [2, 3]. Such configuration suffers some disadvantages as the sensor system will be bulky and complicated thus high stray capacitance effect could easily occur [4]. Therefore, a customized FR4 copper sensor is proposed [1]. This sensor design has the noise driven guards embedded with it as a single independent unit (see Figure 3).

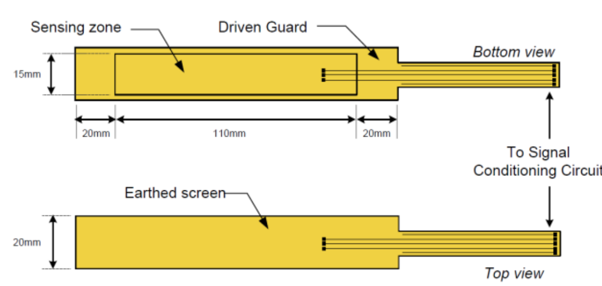


Figure 3 FR4 copper ECT sensor with embedded earthed screen and driven guard

3.0 PREPARATION OF FINITE ELEMENT ANALYSIS

The basis of the finite element method was developed as a way of decomposing complex problems into simple well known parts. The behavior of a physical system is governed by boundary conditions and sophisticated mathematical models. COMSOL Multiphysics software is able to carry out FEM to solve physical systems of immense complexity through approximated simulation of the system geometry.

To evaluate the ECT sensor, two sets of model were considered; ECT sensor model setup with and without the embedded guards. Several steps of FEM are taken to visualize the behaviour of the sensor guard design are:

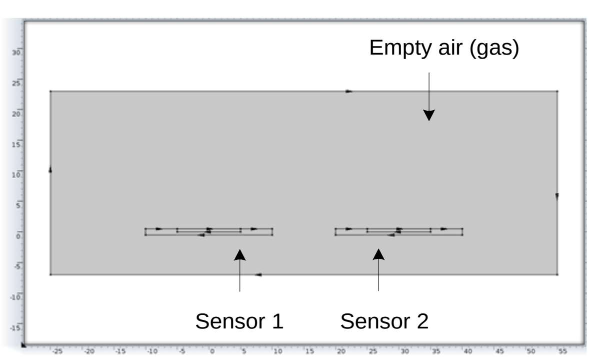
- Sensor geometry modelling
- Material selection
- Boundary settings
- Meshing process

3.1 Sensor Geometry Modelling

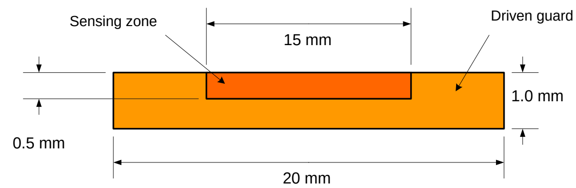
The electrostatic multiphysics is selected for the whole FEM analysis. By using COMSOL, a simulation experiment platform is virtualized in two dimensional view with its actual size and dimension (see Figure 4). The ECT sensor geometry is configured according to parameters in Table 1.

Table 1 ECT sensor parameters for geometry modelling

Parameter	*Value (mm)*
Thickness of sensing zone	0.5
Thickness of driven guard	1
Length of sensing zone	15
Length of driven guard	20



(a)



(b)

Figure 4 ECT sensor geometry model for simulation; (a) two sensors in adjacent position inside an empty air (gas) space, (b) dimension of a single sensor in 2D

3.2 Material Selection

A variety of material selection is available in the material browser inside COMSOL software. The FR4 copper material were applied on the ECT sensor whilst air (gas) material were applied to the surrounding area of the sensor to create a virtual empty air (gas) environment (see Figure 4).

3.3 Boundary Setting

Since the geometry model setting involves several materials, boundary conditions and interfaces between two or more of these materials need to be set accordingly. The dielectric materials in the sensing region have different relative permittivity (ε) where the capacitance sensor needs to measure changes of these values. The capacitance between two electrodes can be expressed by equation 2 [5, 6] while the electric field is given by equation 3 [7].

$$C_{i,j} = \frac{\iint_A \varepsilon(r)\nabla\varphi(r)dA}{\varphi_i - \varphi_j} \tag{2}$$

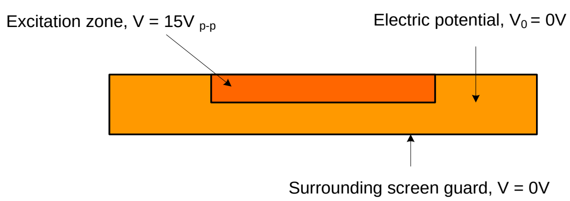
$$E = -\nabla\varphi(r) \tag{3}$$

where $C_{i,j}$ is the capacitance value between electrode i and j, ε(r) is the permittivity distribution in the sensing field, φ(r) is the potential difference value, φ_i - φ_j is the potential difference between two electrodes forming the capacitance and A is the electrode surface area. The boundary conditions used in this formulation is as Table 2 and is further illustrated in Figure 5.

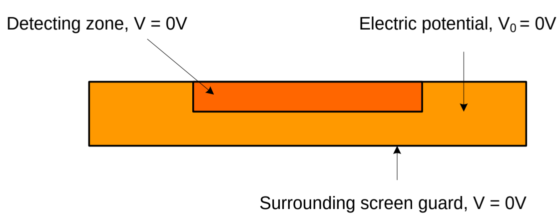
Table 2 Boundary condition of ECT sensor

Description	*Parameter*
Excitation electrode (sensing zone at sensor 1)	V_0 = 15 V
Detecting electrode (sensing zone at sensor 2)	V_0 = 0 V
Driven guard	V_0 = 0 V

In this case, electrical boundary conditions of ground were applied on the detecting zone of sensor 2 while an electric potential of 15 $V_{p\text{-}p}$ applied to the excitation zone of sensor 1. With the boundary conditions in Table 2, the selected electrostatic multiphysic could solve the complex mathematical calculations thus obtain the permittivity distribution within the region of interest.



(a)



(b)

Figure 5 Boundary conditions on (a) Excitation electrode and (b) detecting electrode

3.4 Meshing Process

Finite element meshing technique is used for dividing a complex problem into small elements by breaking down the geometry model into nodes and then connecting these nodes to form triangle elements. This discretization process approximates the ECT sensor geometry model with a total of 22654 elements predefined as extremely fine mesh. The free triangular element ranging from maximum and minimum size of 0.8 mm and 0.0016 mm respectively as in Figure 6.

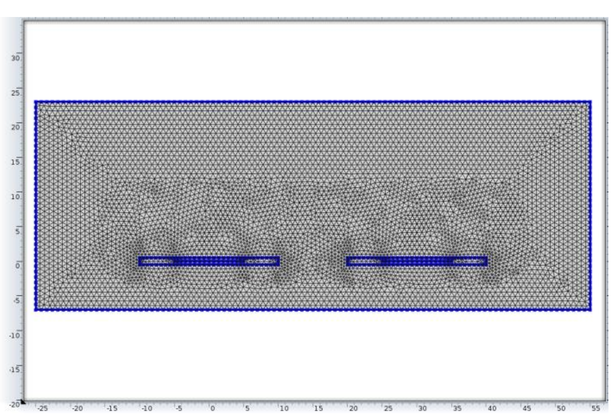
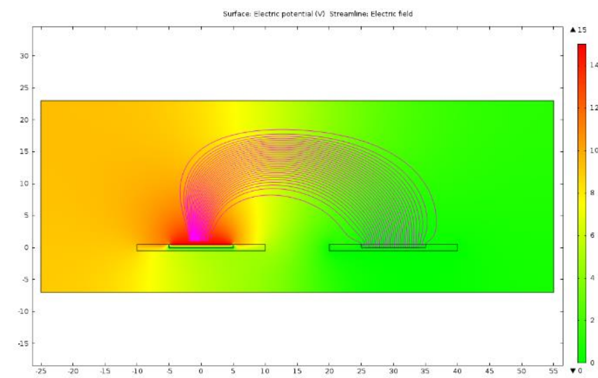


Figure 6 Mesh size parameters with maximum and minimum element size of 0.8 mm and 0.0016 mm respectively

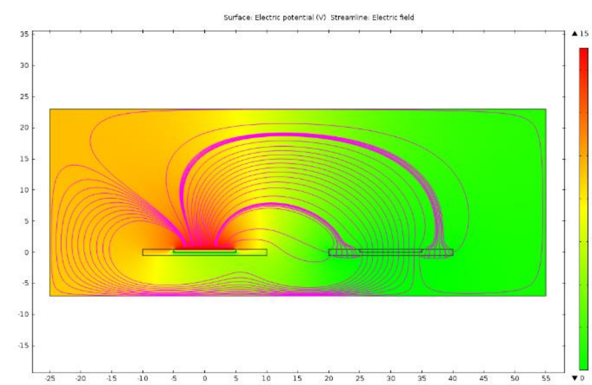
After meshing process, the meshed model is solved using stationary domain solver over each meshed elements.

4.0 RESULTS AND DISCUSSION

The two sets of ECT sensor model setup were solved in this simulated experiment to identify the behavior of the electrodes within an empty air condition. The 2D Results are presented as in Figure 7.



(a)



(b)

Figure 7 FEM electric field streamline pattern (a) with driven guards and (b) without driven guards

Figure 7 (a) shows that the electric field distributed evenly from the excitation sensor towards detection sensor whilst figure 7 (b) shows that the electric field distributed randomly from various directions to the detection sensor. This phenomenon occurs due to the effect of driven guards in aiding the excitation sensor for focused distribution between sensors and further optimize detection strength at the detecting sensor. The FEM results indicate the impotency of ECT sensor without driven guards.

The advantage of this design over the conventional type is that the proposed design has eliminated the use of external radial guard and earthed screen by replacing it with the embedded driven guard which covers the sensing zone. Hence, the proposed ECT sensor with embedded driven guards could practically implement for ECT applications.

5.0 CONCLUSION

An embedded driven guard for ECT sensor has been proposed for tomography applications. These guards have better advantages comparing to the conventional type of design and configuration. Thus, its flexibility to bend makes it easier to attach on curved surface such as circular pipe circumference. The FEM analysis successfully indicates the sensor functionality and its effects in the presents of the embedded guards and without it.

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