Analysis on the Sensitivity Distribution in Electrical Capacitance Tomography System

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Abstract

The sensitivity distribution in ETC may affect the analysis of the permittivity distribution of the multi-phase. However, very limited work has been done in this issue. In order to investigate the sensitivity distribution in ETC, this paper employs the finite element method (FEM) to establish the principle and components of ECT. The FEM model of the sensitivity distribution as a function of the inter-electrode capacitance was discussed. Simulation tests were carried out to calculate the charge on the electrode pairs to access the potential distribution of the ETC. The analysis results show that the dielectric have great influence on the capacitance value and small distance between the electrode pair and the sensitivity field will produce high sensitivity value. Hence, the findings of this work can provide reference for the design of ECT in practice.

Keywords

electrical capacitance tomography, sensitivity distribution, meshes dividing.

1. Introduction

Electrical capacitance tomography (ECT) is a relatively mature imaging method in industrial process tomography [1-3]. The aim of ECT is to image materials with a contrast in dielectric permittivity by measuring capacitance from a set of electrodes. Applications of ECT include the monitoring of oil-gas flows in pipelines, gas-solids flows in pneumatic conveying and imaging flames in combustion, gravitational flows in silo.

A typical three-dimensional capacitance sensor comprises an array of conducting plate electrodes, which are mounted on the outside of a non-conducting pipe, and surrounded by an electrical shield. For a metal wall pipe/vessel, the sensing electrodes must be mounted internally, with an insulation layer between the electrodes and the metal wall and using the metal wall as the electrical shield. Other components in the sensor include radial and axial guard electrodes, which are arranged differently to reduce the external coupling between the electrodes and to achieve improved quality of measurements and hence images. As usually, the electrodes do not make physical contact with the materials to be measured, ECT provides a non-intrusive and non-invasive means, avoiding the risk of contamination.

In the research of electrical capacitance tomography system, sensitive field by the multiphase flow effects of medium distribution, that is, the soft field characteristic brings great difficulty for image reconstruction. The permittivity distribution is very important to the flow pattern. ETC can acquire the permittivity distribution of the multi-phase. The sensitivity distribution in ETC system may affect the analysis of the permittivity distribution of the multi-phase.

This paper employs the finite element method (FEM) to establish ECT simulation model and hence to investigate the sensitivity distribution. The influence factors of the ECT parameters have been discussed in this work.

2. Research Method

Basically, an ECT system works based on Poisson's equation given by:

$$\nabla \cdot (\varepsilon(x)) \nabla \Phi = -\rho(x) \tag{1}$$

Where $\varepsilon(x)$ is the permittivity distribution, Φ is the electrical potential and ρ is the charge potential. Meanwhile, the electric field is given by:

$$E = -\nabla \Phi \tag{2}$$

By applying Gauss law, the induced charge at electrode j when electrode i is the source electrode can be calculated using:

$$Q_{ij} = \oint_{\Gamma_j} \varepsilon \cdot \widehat{E} \cdot \hat{n} d\ell = \oint_{\Gamma_j} \widehat{D} \cdot \hat{n} d\ell \tag{3}$$

where Γ_j is the closed curve enclosing the detector electrode and $\hat{n}$ is the unit normal vector to Γ_j. Given charge Q_{ij}, the capacitances for all possible pairs of electrode combinations can be calculated using the equation:

$$C_{i,j} = \frac{Q_{ij}}{U_{ij}} \tag{4}$$

Where, U_{ij} is the voltage between the source electrode i and the detector electrode j.

For the ECT system with N electrode plate, the independent electrode can be obtained on a total of n:

$$n = \frac{N(N-1)}{2} \tag{5}$$

In order to reduce the influence of various interference of capacitance value, the plate of the capacitor value is normalized. The capacitance normalized value is $C_{i,j}^{N}$, then the:

$$C_{i,j}^{N} = \frac{C_{i,j} - C_{i,j}^{l}}{C_{i,j}^{h} - C_{i,j}^{l}} \tag{6}$$

Where, $C_{i,j}^{l}$ is the capacitance value of i, j plate for all units in the pipeline for the low dielectric constant; $C_{i,j}^{h}$ is the capacitance value of i, j plate for all units in the pipeline for the high dielectric constant.

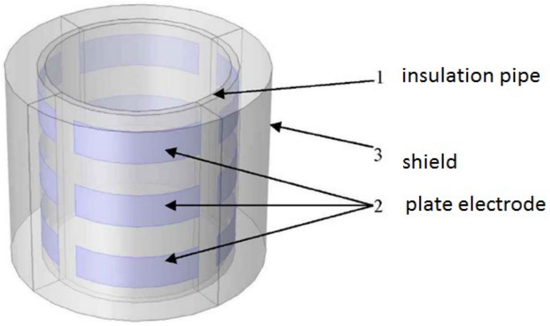
ECT sensitive field distribution for each electrode capacitance sensitivity on the distribution of description, image reconstruction with the sensitivity distribution as prior knowledge. Suppose the whole cross section of the pipeline is divided into m units, unit 1~m in the internal pipeline. The sensitivity of the essence is the change of capacitance caused by the dielectric constant of a unit change occurs. K defines a unit relative to the i, the sensitivity of j plate on the values of $S_{i,j}(k)$ for:

$$S_{i,j}(k) = \mu(k) \cdot \frac{C_{i,j}(k) - C_{i,j}^{l}}{(\varepsilon_h - \varepsilon_l)\left|C_{i,j}^{h} - C_{i,j}^{l}\right|} \tag{7}$$

Where, $C_{i,j}(k)$ is the capacitance value between electrode pair i-j when the k element is filled with higher permittivity material in the lower permittivity background and $\mu(k)$ is an area correction factor, which is assigned to the ratio of the area of the largest element to the area of the k element [3].

3. Results and Analysis

In this paper a 12-eletrode ECT sensor has been used with 3 planes and 4 electrodes on each plane. The electrode arrangement used in this study is 12 electrodes 3D ECT system that has been depicted in Fig. 1. Among them, the axial length is 9 mm, plate axial distance between 9 mm, tube high 54 mm, 23 mm radius of pipe, pipe outer radius of 25 mm, shielding enclosure radius of 33 mm.



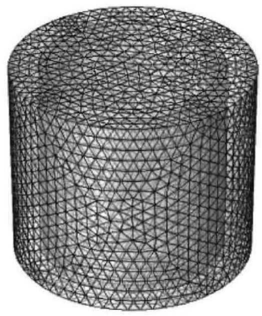


Fig. 1 12 electrodes array for 3D ECT system Fig.2 The finite element mesh

3.1 meshing

Finite element analysis using free tetrahedron grid subdivision, grid subdivision diagram is shown in Fig 2. The unit number is 65637.

3.2 Empty and full capacitance value research

In the process of direct 3D ECT reconstruction, the need to measure all provided and different layer capacitance value: when 1 plate for incentive plate, you may need to measure the plate for 1-2, 1-3,...And capacitance values between 1 and 12.When 2 plate for incentive plate need to measure plate for 2-3, 2-4,..., capacitance value between 2 and 12, until 11 incentive plate for plate, measuring capacitance between the plate on 11-12.So in 12 plates direct 3D ECT system need to measure the number of independent capacity for 66.Model in the wall of the dielectric constant is set to 4, when the pipe of dielectric constant is set to 1, Empty capacitance value can be measured system. The dielectric constant when the pipe is set to 2.6, full capacitance value can be measured system. Some empty and full capacitance values in Table 1.

Table1 Empty and full capacitances（fF）

Electrode pair	Empty capacitance	full capacitance
1-2	130.4908	200.9159
1-3	16.5883	42.1461
1-4	130.4718	200.8855
1-5	270.8393	342.2448
1-6	34.1865	65.8936
1-7	9.0269	23.8338
1-8	34.3964	66.1641
1-9	8.2368	21.8551
1-10	5.1484	14.2398
1-11	3.3743	9.7550
1-12	5.1451	14.2315

According to the data in Table 1 can be draw the curve of the empty and full capacitance distribution(Fig.3).

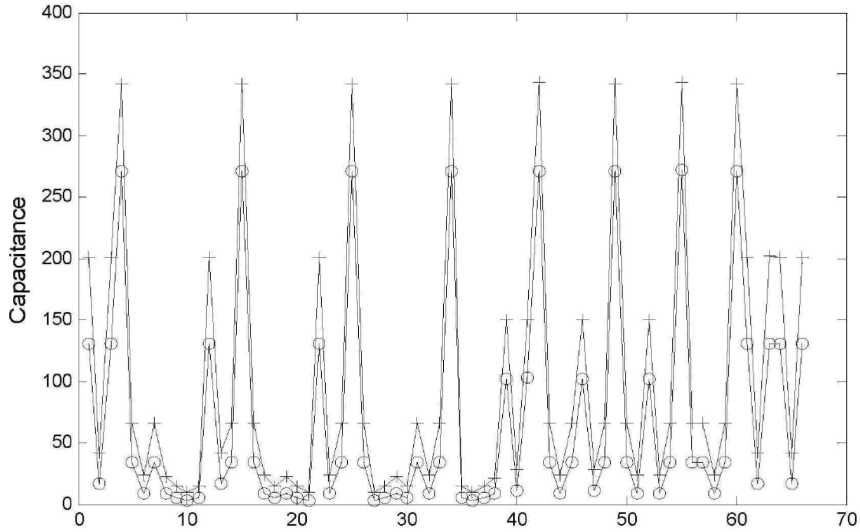


Fig.3 Graph of empty and full capacitances

3.3 sensitivity distribution

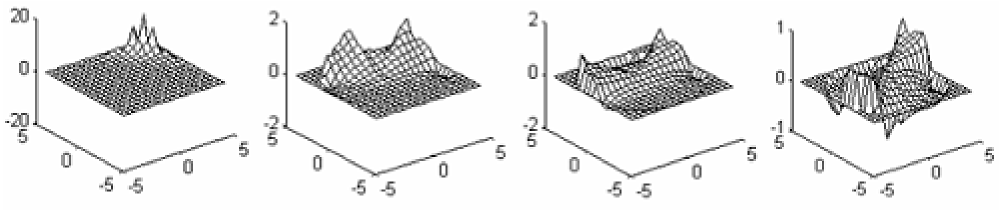


Fig. 4 sensitivity distribution

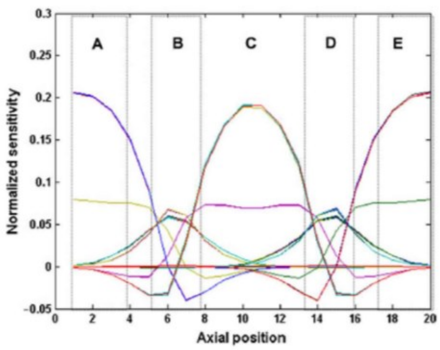


Fig.5 Schematic of axial sensitive strength

By Fig 4 shows, when the dielectric constant of epsilon h material close to the electrode pair, enhanced the sensitive field, in some areas, because of the influence of the soft field effect, is near the peak appeared negative spike in sensitive field, namely somewhere for large dielectric constant capacitance between the plate decreases. Negative sensitive area in is in conformity with the actual, negative numerical simply as a sensitive area cannot be zero. These kind of nonlinear characteristics also ECT system is different from an important aspect of X-ray imaging. Its reason mainly is the capacitance is a curved shape projection imaging, in this case, the power distribution of the electric flux of the electrode time decreases, and thus reduces the capacitance value. This nonlinear will make imaging image distortion is produced.

By the above analysis it can be seen as a kind of nonlinear distribution of sensitivity field, the field distribution in regional distribution, capacitance change focused on two plates relative area, and a saddle shaped, the nearer the plate sensitivity is higher, the capacitance change with the change of medium, the more obvious. The sensitivity in the central regions of the pipeline was obviously lower sensitivity than the near wall area.

Fig. 5 for typical axial normalized graph, sensitivity curve reflects the strength of different position sensitive area. Area A and E are called "blind spots", because of the sensitivity can be ignored in A shaft up change, cannot provide reconstruction goal axial location information. Area B and D are called "weak sensitive area", sensitivity has small changes in shaft upward, can provide reconstruction target axial position with a small amount of information. Area C for "strong sensitive area", axial changes to determine the sensitivity of the region has a decisive influence to rebuild the location of the object.

4. Conclusion

Sensitivity of the change is in the process of image reconstruction determine different position are the important factors of dielectric constant, the plate cover only limited areas in the sensitive field, some areas not covered by plate, which could produce sensitive "blind spot" in the field. Field grid subdivision is the basis of the capacitance sensor sensitivity field analysis, and sensitive field characteristics for a detailed understanding of the soft sensor field, provides the basis, and in improving reconstruction image quality and research of new image reconstruction algorithm is of great significance.

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