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An introduction of two differential excitation potentials technique in electrical capacitance tomography

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ABSTRACT

The investigation of this work is to analyse the sensitivity distributions using single and two differential excitation potentials techniques in order to improve the situation of: (1) non-uniform sensitivity distribution; (2) less sensitivity in the central area, and (3) non-linear change in the ECT (electrical capacitance tomography) system. Forward modelling using COMSOL Multiphysics is developed in order to obtain an algorithm to quantify the image reconstruction. The forward model developed is to simulate the changes in capacitance between opposing electrodes and the permittivity of the dielectric material due to the increasing of the diameter of a higher permittivity insert when two differential excitation potentials were injected. The MATLAB simulation is used to obtain the sensitivity distribution inside the closed pipe from the sensor. By using the MATLAB software, the forward model conditions are placed on the image plane to estimate the results. Generated phantoms and measured values are presented. Simulation is verified using available experimental data through the existing system, sixteen-segmented ECT sensor electrodes. By using this technique, the linear relationship between the capacitances measured and the permittivity dramatically improved, and the sensitivity distribution for an opposing electrode pair was increased; thus giving a slight increase in the sensitivity distribution in a central area. Simulation and initial experimental results illustrate the capability of the technique presented.

1. Introduction

Initially, tomography was applied in the medical field for diagnostic purposes. In medical applications, X-rays were used as a radiation source to form images of bones based on their attenuation coefficient. This approach allows us to 'see' the internal structure (bones) of our body without 'opening' it. Therefore, a tomography approach is also known as a non-invasive method to investigate the internal structure or behaviour of a material. It has to be emphasised that the concept of tomography is not restricted to the medical field. This fundamental difference results in differences in sensor design, imaging speed, image reconstruction algorithms and also cost [1].

Electrical capacitance tomography (ECT) is the most mature among many different industrial tomography modalities. It has been developed rapidly and used successfully in many applications, mostly for multiphase flow measurement. Research work has proven that this technique is one of the most attractive and promising methods for the measurement of two-phase flow because of its non-invasion, reliability, simplicity and high-speed capabilities [1–3]. There are three principal difficulties with image reconstruction for ECT: (1) the relation between the permittivity distribution and capacitance is non-linear and the electric field is distorted by the material present, the so-called 'soft-field' effect [1,2,4]; (2) the sensitivity in a different location between the electrode pair does not give a uniform sensitivity distribution. Note that the maximum sensitivity of an adjacent electrode pair is 100 times larger than of an opposing electrode pair [1]; and (3) the sensor is more sensitive in the wall area than the central area, and consequently, the signal-to-noise ratio (SNR) in the central area is poor. This effect will cause the mutual capacitances to be so small; thus the electrode charges

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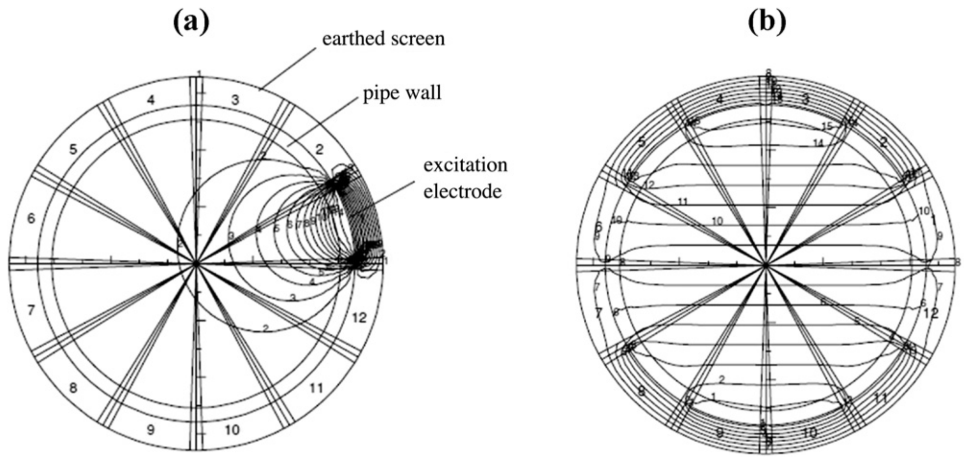

Fig. 1. Electrical field distributions within a 12-electrode sensor (a) single-electrode energised and (b) parallel field generated by applying excitation signals to all electrodes.

(and their change) can also be very small, and as a result, the SNR of the measurements tends to be rather poor [5].

An ECT sensor consists of a set of measurement electrodes mounted symmetrically inside or, more typically, outside an insulating pipe. In the conventional measurement scheme, only one voltage source is applied to each of the sensor electrodes in turn with the remaining electrodes kept at ground potential, and the capacitances between all electrode pairs measured. This is called the single-electrode excitation scheme, and the electrical field distributions of the sensor can be seen in Fig. 1(a) using a single-electrode energised within a 12-electrode.

It has been stated that the sensitivity is proportional to the electrical field strength. To improve the sensitivity and SNR (signal-to-noise ratio) in the central area, a scheme called parallel field excitation has been proposed previously by [4,6,7], in which the parallel field is generated by applying excitation signals to all electrodes. However, if excitation signals are applied to multiple electrodes, it is possible to generate a parallel field with an ECT sensor as shown in Fig. 1(b). The sensitivity maps of a parallel-field ECT sensor are simply linear superimpositions of the sensitivity maps of the conventional ECT sensor, and a parallel-field ECT sensor does not give a uniform sensitivity distribution. This has been confirmed by theoretical analysis, software simulation and experiments [1].

In the case of a sensor with internal electrodes, the components of capacitance due to the electric field inside the sensor will always increase in proportion to the material permittivity when the sensor is filled uniformly with higher permittivity material. The wall has a negative effect on the measurement of the internal capacitance because the wall capacitance is effectively in series with the internal capacitance [4]. However, for sensors with external electrodes, the permittivity of the wall causes non-linear changes in capacitance, which may increase or decrease depending on the wall thickness and the permittivities of the sensor wall and contents [8].

From previous studies there are no techniques to improve the uniform sensitivity distribution in the central area and improve the level of the detection signals in the ECT system using single electrode excitation and one voltage source. Thus, the focus of this work is to analyse the sensitivity distribution and non-linear changes of capacitance due to increasing the diameter of the higher dielectric material. Instead of using only one potential excitation/voltage source to an excitation electrode at a given time, a two difference potential excitation/voltage source, applied sequentially to difference excited electrode pairs, is introduced, to produce an approximately uniform excitation field across the sensor. The simulations of image reconstruction are presented to show the capability of these techniques in improving the sensitivity distribution in the central area. These techniques have not been used before in an ECT system. The increase in voltage across the centre of the pipe should improve the SNR (signal-to-noise ratio) compared to that achieved using standard single excitation potential schemes.

2. Modelling process using COMSOL Multiphysics

For most practical ECT sensors, there is not a simple linear relationship between the capacitances measured inter-electrodes and the permittivity of the material inside the sensor. The relatively large number of different measurements required and the fact that the relationship between capacitance and permittivity may be different for each of these measurements creates potential calibration and operating problems for ECT systems. The relationship between capacitance and permittivity distribution is governed by the following equation:

$$C = \frac{Q}{V_c} - \frac{\oint_s \varepsilon(x,y)\nabla\varphi(x,y)ds}{V_c} \qquad (1)$$

where $\varepsilon(x, y)$ is the permittivity distribution in the sensing field, V_c is the potential difference between two electrodes forming the capacitance, $\varphi(x, y)$ is the potential distribution and S is the electrode surface or close line.

However, the permittivity distribution is generally not uniform [2]. In ECT this is usually referred to as a forward problem. A forward problem is the process of determining the output response of an ECT system when the permittivity distribution is known.

Thus, this non-linear forward problem has been simplified to a linear approximation. The method which is commonly used to overcome these problems is to restrict the use of ECT to the case where the sensor contains mixtures of two materials of differing permittivities and to operate the ECT system between the range of permittivities of these two materials. This is done by calibrating the sensor before any measurements are commenced, and involves first filling the sensor with the lower permittivity material and measuring all the inter-electrode capacitances, and then repeating this operation with the higher permittivity material. All subsequent capacitance measurements are then referenced (or normalised) to the values measured at calibration. For example, all the capacitances have normalised values '0' when the sensor contains the lower permittivity material and '1' when the sensor is filled with the higher permittivity material. For all other conditions, the capacitances will have values which nominally lie between these two measurement limits.