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Performance Analysis of AC-DC Electrical Capacitance Tomography

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ABSTRACT: The electrical capacitance tomography (ECT) is a method to determine the material distribution within the interior of a closed object by measuring the capacitance value across externally mounted electrodes. This paper investigates the electrical capacitance tomography measure up to performance of triangle wave (AC) and charge-discharge (DC) methods. AC-DC based method applying voltage to the ECT sensor with different time. An excitation signal is applied to a pair of electrodes that forms a capacitor during each measurement step in order to determine the capacitance from the output current measured. When the voltages is applied to the pair of electrodes, the analyzing charging and discharging time and quality of the output signal. The betterment of the ECT system need to avoid stray capacitance then increase speed to switching combinational electrodes. This paper presents finally, the output voltages are also convert into images by using MAT Lab.

KEYWORDS: Electrical Capacitance Tomography; Triangle wave method; charge-discharge method; MAT lab; AC-DC signal.

1 INTRODUCTION

The term tomography refers to process of exploring the internal characteristics of a region through integral measurements related to internal characteristics of specified domain. There are different types of tomography techniques available in industries. Generally there are two types of tomography available, they are: Direct tomography and indirect tomography. In indirect method, visual recording which are not visible to human eye are use. While in direct method, the visual recordings are visible to human eye. Electrical Capacitance Tomography (ECT) is a non intrusive, non invasive and radiation free technique. They have application in industry, medical imaging, geophysics, biology etc. Industrial Tomography is an emerging technique used to visualize internal behavior of industrial processes such as gas/ oil/ water flows in pipelines, pneumatic conveyors and in mixing/separation processes. The flow of liquid in industry is a complex and random mechanism. The inter electrode capacitance measurement provide the spatial distribution of mixture of dielectric materials inside the vessel/PVC tube. These values are converted to pixel an there by image is obtained. This shows distribution of permittivity between the electrodes. The images are generated in high speed, but they are approximate and of relatively low resolution. Although it is possible to image vessels of any cross section, most of the work to-date has been carried out on circular vessels. The different techniques used for capacitance measurement [1-5].

The various methods such as charge-discharge, AC based capacitance measurement for capacitance measurement and review the main inadequacy of the system. A better performance of ECT can be achieved by reducing the measurement noise. The charge-discharge method, charging and discharging currents from the multiple cycles are integrated using two integrators. This method is insensitive to the stray capacitance. The charge-discharge circuit is a well suited circuit for a small capacitance measurement due to its immunity to noise and stray capacitance, although it has a problem associated with a charge injected by the analogue switches, which results in a dc offset [16]. AC based capacitance measurement circuit has been widely employed in ECT system because of its reason low drift, good linearity, and high signal to noise ratio. The ac based capacitance measurement circuits, to determine accurately the unknown capacitance from the ac signal. The traditional AC-based ECT method applies at each time instance an excitation signal to one of the 8 electrodes and measures the voltage at one of the other electrodes to determine the inter-electrode capacitance [6-10]. As a result, only one capacitance value is measured at each measurement step. Such a sequential, single-excitation-single receiving method is time consuming, especially when M is large. Efforts in speeding up the frame rate in recent years have focused on hardware optimization to minimize delays during the signal conditioning process and reduce the time period for each measurement step [11-15].

2 PRINCIPLE OF ECT SYSTEM

The principle of this sensor is that, when the dielectric medium changes, the capacitance value also gets changed. Basically any two adjacent conductors can be considered as a capacitor, and different dielectric properties between the conductors will create different capacitor values. The sensors usually consist of two electrode plates and the capacitance. The relationship between the capacitance and the permittivity distribution is governed by the following equation.

$$C = \frac{Q}{V} = \varepsilon_0 \varepsilon_r \frac{A}{D} \qquad (2.1)$$

Where,

ε_0 - The permittivity of vacuum,

ε_r - The relative permittivity of the material inside the sensor

A - The area of the plates,

D-is the distance between the two plates.

ε_o and ε_r are the global average of the fluid dielectric property over the entire sensing volume of the sensor or better known as permittivity. If the area of the plate and the distance between them are known and by measuring the capacitance; we can effectively measure the dielectric constant. In this case, capacitance value is proportional to the permittivity in between the electrodes.

3 PROPOSED WORK OF ECT SYSTEM

3.1 CHARGE\DISCHARGE BASED MEASUREMENT

The simplified circuit diagram of charge/discharge circuit is shown in Fig-1. The DC source voltage is applied to the measured capacitance. The capacitance is charged and discharged based on clock frequency. The capacitance circuit acts as a low pass filter. The signal from the charge/discharge circuit has to be further amplified by DC amplifier to predict the sufficient output. The charge current flows for the voltage source (V_c) through the measured capacitance (C_x), to op-amp 1 with resistance feedback (R_f). The charge transferred to op-amp 1 is

$$Q_1 = V_c C_x. \qquad (3.1)$$

Considering the charge frequency, the charge current flowing into op-amp 1 is

$$I_1 = f\, Q_1 = f\, V_c C_x. \qquad (3.2)$$

Op-amp 1 converts the current into a voltage, thus

$$V_1 = -I_1 R_f = -f\, V_c C_x R_f \qquad (3.3)$$

Considering the op-amp offset, the output of op-amp 1 is

$$V_1 = -f\, V_c C_x R_f + e_1. \qquad (3.4)$$

Similarly, during the discharge phase, switches S2 and S3 are closed and switches S1 and S4 are open. The charge stored in the measure capacitance discharges, i.e. the left side of C_x discharges to ground and the right side draws current from op-amp 2. Op-amp 2 converts the current into a DC voltage

$$V_2 = f\, V_c C_x R_f + e_2. \qquad (3.5)$$

Where, e_2 is the op-amp offset. A differential amplifier with a gain of K is used to sum these two signals, producing a DC measurement signal proportional to the measure capacitance.

$$V_{out} = K\,(V_2 - V_1) = 2K_f\,V_c C_x R_f + K\,(e_2 - e_1) \qquad (3.6)$$

The net voltage is proportional to the unknown capacitance**.**

This method is simple and low cost but the charge injection problem from the CMOS switches occurs and also dc amplifiers suffer from the drift problem. This is due to increase the measurement error and reduces the sensing speed to 300 frames per second. The error arises from charge injection from CMOS switches and op-amp offset voltage. The sensitivity of the charge/discharge circuit is proportional to the charge/discharge frequency. To maximize the measurement sensitivity, the output of the circuit must be as large as possible. The clock should be operated at high frequency that does not cause a reduction in gain. The stray capacitance is typically of the order of 150 pf, of which 100pF may be caused by the screened cable connecting the electrode to the charge/discharge circuit. Therefore a high charge/discharge frequency is desirable. This frequency can be as high as 2.5 MHz, which is limited by the CMOS switches.

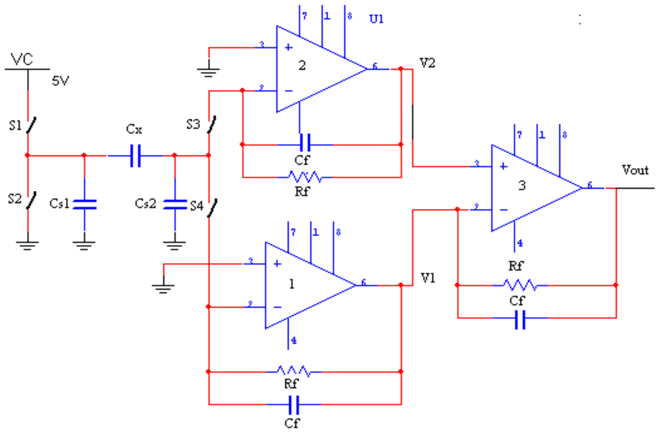

Fig. 1. The charge/discharge capacitance measuring circuit

3.2 A.C. BASED CAPACITANCE MEASUREMENT

The simplified circuit diagram of AC based measurement circuit is shown in Fig.2. The triangle excitation signal is produced by the signal generator with its amplitude and frequency and then applied to an electrode. The charging voltage detected by an op-amp with capacitive and resistance feedback circuits. It is further amplified by the programmable gain amplifier and then demodulated by the phase sensitive demodulator consisting of an analogue multiplier followed by the low pass filter. . A sine-wave voltage (V_i) used as the excitation source is applied to the measured capacitance (C_x), producing an AC voltage with varying amplitude and phase angle. The signal has to be further conditioned by AC amplifiers, a demodulator (i.e. rectifier or phase-sensitive demodulator (PSD) and a low –pass filter to obtain a DC signal representing the unknown capacitance. The op-amp with capacitance and resistance feedback (C_f, R_f) converts this current into an AC voltage (note that resistance feedback is necessary to prevent the op-amp output drift, which would eventually saturate the op-amp).

Then

$$V_o = \frac{j\omega C_x R_f}{j\omega C_f R_f + 1} V_i \qquad (3.21)$$

where, ω is the angular frequency of the sine-wave source.

If a large value of R_f is selected so that | $j\omega C_f R_f$ | >>1 (for example, if $\omega = 2\pi$500x 10^3, i.e. C_f = 500 kHz, R_f =1MΩ, then that | $j\omega C_f R_f$ | >>1), equation (3.21) becomes

$$V_o = -\frac{C_x}{C_f} V_i . \qquad (3.17)$$

Therefore the AC-based circuit produces an AC signal with a magnitude proportional to the measured capacitance. The main difference between the charge/discharge and AC based circuit lies in the positions of the demodulators.

The AC based capacitance measurement reduces the drift problem and provides high signal to noise ratio. The stray capacitance affects both the magnitude and phase of the output. The stray capacitance varies between 90 and 210 Pico farad, the measurement error would be between +0.03% to –0.1%. The amount of stray capacitance sensitivity solely related to the on resistance of the CMOS switches, gain of the detection circuit and overall measurement error of the system. The other non-ideal parameter in the AC based capacitance measurement such as the op-amp voltage and current noise, drift gain-bandwidth product and stability of the feedback capacitor C_f. The measurement system will be affected at the high frequency range, since the AC based capacitance measurement circuit is used only for low range excitation source.

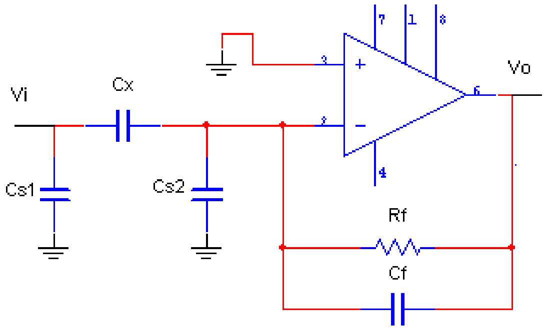

Fig. 2. AC-based capacitance measuring circuit with stray capacitances

4 Result Discussion

4.1 Image Reconstruction using Mat lab

The output voltage varies proportionally to the measured capacitor's significant value. Thus the result is established to speed enhancement in the projected ECT system. ECT system with a help of Real time values are to convert images. Linear Back Projection Algorithm is based on the solution of a set of forward and reverses linear transforms. The two problems concerned are finding the permittivity inside a pipe when the capacitance values are measured which is usually referred to as forward problem. The second problem is to find the capacitance value when the permittivity inside a pipe is known. The normalized capacitance value and sensitivity maps are used to find sensitivity at one plate. After finding sensitivity at one plate, we rotate the plate and similarly find sensitivity at each 45 degree rotation. After this, combination values need to be calculated and plot it in color code. We can also find overall sensitivity of the system in similar way and produce the overall sensitivity image plot. The two method output voltages are used to reconstruction image of air and urea medium inside the tube.

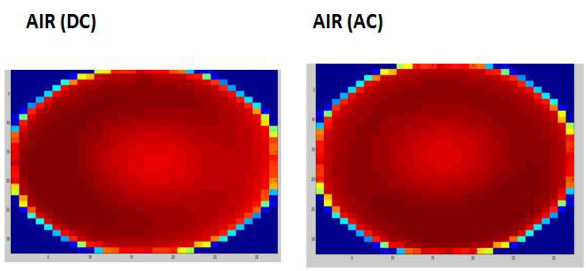

Fig. 3. DC and AC method images for AIR medium

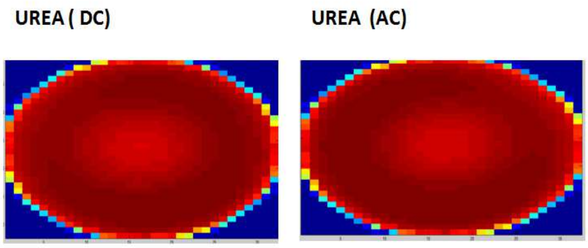

Fig. 4. DC and AC method images for UREA medium

5 CONCLUSION

The aim of this paper evaluates betterment method of ECT system. The charge discharge measurement method is simple and low cost but the charge injection problem from the CMOS switches occur and also DC amplifiers suffers from the drift problem. This is due to increase in the measurement error and reduces the sensing speed 300 frames per seconds. The AC based capacitance measurement reduces the drift problem and achieves signal to noise ratio. The stray capacitance affects both magnitude and phase of the output. The amount of stray capacitance sensitivity solely to the on resistance of the CMOS switches, gain of the detection circuit and overall measurement affect at high frequency range. Finally, reconstruct the image of air and urea medium using MAT lab. The results of above method performances have some drawbacks. So, we can look forward working the fast active differentiator method.

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