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ELECTRICAL CAPACITANCE TOMOGRAPHY SYSTEM

[1]**Merin Susan Soji,** Dept. of Electronics and Instrumentation Engineering, JJ college of Engg
[2]**K.Manikandan,** Dept. of Electronics and Instrumentation Engineering, JJ college of Engg
[3]**S.Sathiyamoorthy,** Dept. of Electronics and Instrumentation Engineering, JJ college of Engg
Mail: [1]merinsusan88@gmail.com, [2]kmanirec@gmail.com,[3]sathyajayam@nitt.edu

***Abstract*: Electrical Capacitance Tomography is a non intruding technique used in industries. It is based on measuring the capacitance of multi-electrode ECT sensor produced by the change in dielectricity or due to change in concentration of material. With the use of computed values, a cross sectional image of the material placed in the dielectric medium is obtained. ECT system can be used in chemical field, industrial field and pharmaceutical and oil industry and for homeland security. In the paper presented here, operation principles and calibration methods of ECT system is discussed. The system is calibrated under certain conditions to find the relation between values indicated by measuring instrument or system or values represented by a materialised measure or reference material and values realised by measurement standards.**

***Keywords*- ECT sensor, multi-electrode, dielectricity, calibration method**

I. INTRODUCTION

Electrical Capacitance Tomography[1][2] (ECT) gives cross sectional image of the material placed between the dielectric medium. It is a method for finding the permittivity of the material placed inside the medium, based on exterior capacitance measurements. The inter electrode measurements is taken by placing the electrodes around the dielectric medium, which is usually placed inside of a PVC pipe and the medium to be imaged is present inside the PVC cylinder. A stable AC signal is applied a pair of electrodes that form as capacitor during each measurement step. The obtained voltage values is converted to equivalent capacitance values and used for imaging the material. ECT has been used widely in industrial, chemical, pharmaceutical and oil industries. An ECT measure the capacitance electrodes mounted around a PVC pipe, the electrodes are of equal length, area of cross section and evenly placed. The capacitance values between electrodes are measured to know the distribution of dielectric. The system can also be used in the process flow measurement. The capacitance of the sensor will change when the mean dielectric constant between the electrodes changes. This change is due to variations in the percentage of air and liquid flowing in the PVC pipe. The system can also be used in multi phase flow systems (MPF'S)[3]. The presented system is an 8 electrode system and measure capacitance in the range of femto farads, voltage in the range of volts. The system is provided with multiple excitation signal which improve speed of inter electrode capacitance measurement and system performance. The importance of ECT system lies in the fact that the measurement can be completely non-invasive when the vessel is non-conducting. Based on the [principle, the vessel can be of any shape and any cross section can be imaged. The system need to be calibrated with a measurement standard. The calibration is the process of finding the relation between the response of the ECT system and the input quantity, which is from a standard measurement. Thus it can be regarded as including the process of adjusting the output or indication on measurement instrument to agree with the value of applied standard, with a specified accuracy. Thus calibration is the method for tuning our device to work more accurately and precisely.

II. OPERATION PRINCIPLES

The Electrical Capacitance Tomography (ECT) sensor[4][5] system is based on the use of array of 8 electrodes. The electrodes are mounted on a PVC pipe and each electrode is equally spaced and has fixed area. The medium or object to be imaged is placed between the electrodes. For imaging the medium, the measurement circuits are directly connected to the sensor electrodes. This simplifies the measurement of inter electrode capacitance value and therefore become a good design solution for ECT sensor. The 8 electrode system can be used in multi phase flow (MPF's) measurement. The sensing methods used in the presented system can measure the capacitance in femto farads and voltage in micro farads. The mode of excitation is multiple excitations which improves the system performance of the presented AC based ECT system. The proposed system mainly consists of three parts. The main parts are: (1) Sensor system. (2) Capacitance measurement unit. (3) Computer. Thus the main functions of the ECT system can be described as selecting or receiving the signal. Measuring each combination of capacitance values and saving them. On finishing it, it reconstructs and display the image created based on the measured values.

The sensors are made of 8 electrode wound around the PVC pipe. The electrodes are rectangular in shape, equally spaced and have same area of cross section. Sensors used in ECT system are designed according to the cross section of the vessel and positioning of electrode. The pipe of the proposed system was non conducting material with the sensors wound around the pipe which are conducting plates. Thus the sensors are non intrusive and easy to design.

The functional base of an ECT system lies in the fact that the changes of measured capacitance values will depend on the material distribution inside the pipe. Thus the system is not subjected to extreme temperature and high pressure inside the tube. Also, the number of electrodes in a system is inversely proportional to image acquisition rate and overall resolution. However change in capacitance is directly proportional to change in permittivity inside the pipe. The sensor constructed here has pipe outer diameter as 24.5mm and inner diameter is 23mm. The total length of the electrode is about 1000 with single electrode width at 1mm.

III. AC BASED CAPACITANCE MEASUREMENT SYSTEM

Acquisition of capacitance values[6] are done by applying a voltage to one electrode, say electrode 1 while keeping all other electrodes (here electrode 2 to electrode 8) at zero potential. Then charge between each pair of electrode is measured, say electrode 1 and electrode 2. After taking all the possible combinations, consider electrode 2 and give voltage to it. While doing this, keep all other electrodes starting from 3 to 8 at zero potential. Then the charge in these combinations is also measured. This procedure goes on until the electrode 7 is energized and charge in electrode 8 is measured. Thus at the end of calculation there will be a combination of $n * \frac{n-1}{2}$ measurements, i.e., here it is n=8. Therefore, the number of possible combinations is 28. Thus, there will be 28 different voltage values instead of capacitance. Using these values, reconstruction of image is done by making use of any image reconstruction algorithm [7][8], like LBP, Iteration. Landweber's Algorithm etc. The measured voltage values may contain noises and extremely small values. This leads to the need of normalisation. Also the effect of errors inside the unit like offset and drift eliminated. This also makes the calibration of ECT system easy. The basic equation that governs the system is given below

$$C = \varepsilon_0 \varepsilon_r A/d \qquad (1)$$

The AC based system[9][10] used is shown in the figure1. The stable AC signal model provides a fixed frequency and constant voltage to each combination electrode of the proposed system. The basic equation governing the stable AC signal model is based on capacitive reactance. The reactance of the capacitor is decreased by using this technique.

If, $X_c = capacitive\ reactance$, F is fixed frequency and

$$X_c = \frac{1}{2\pi FC} \qquad (2)$$

Therefore if, F is of high value, X_c will have a low value. Thus it is found that, if F value is increased, the X_c value will be negligible. This point to the fact that, the increase in combinational electrode switching speed ensures quality output signal. Using this signal we can construct a clear image.

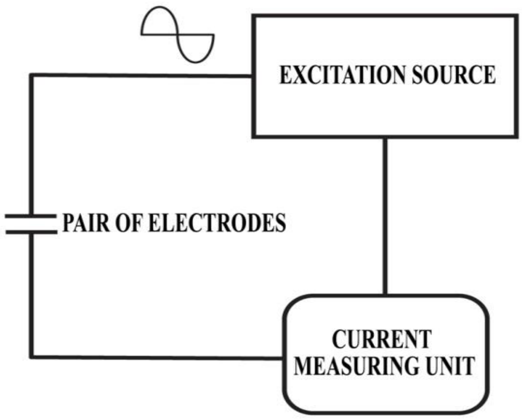

Figure 1: AC based capacitor measuring circuit.

The current voltage convertor device detects and converts the current signal to voltage signal. The current signal and voltage signal are directly proportional. The wide range of sensors available in market works , based on the current and voltage range and environmental impact on the system. It is also known that only specific sensor can be sued for specific application. A current sensing resistor is considered to be a current to voltage convertor which works by inserting a resistor into current path and converting it to equivalent voltage. The sensor is as shown in figure 2. The sensor is the connecting line between load and ground. In nomal case, the sensed voltage is so small that it needs to be amplified using op amps to get measurable output voltage, V_{out}.

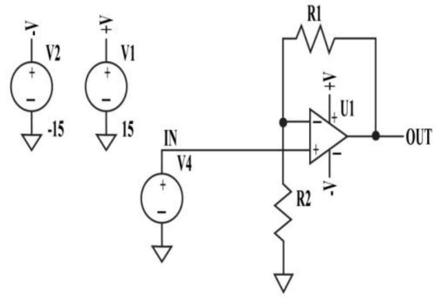

Figure 2: current to voltage converter

IV.

ALIBRATION TECHNIQUE

Instruments are calibrated to make it precise and work accurately. There are number of methods to calibrate[10][11] any instrument. Calibrating an Electrical Capacitance Tomography Sensor can be done by several methods. For that the measurements are done using standard capacitance box. The standard capacitance box has fixed capacitances and the corresponding voltages are measured. Then we took the measured values and founded the relation between capacitance and voltage using Online Regression Tool. The system uses auto correlation and regression method internally to find the relation of voltage and capacitance. The equation derived using Regression Tool is

$$C = (K_1V^n) + (K_2V^{n-1}) + . . . + (K_nV^0) \qquad (3)$$

Here C is the capacitance vales of standard capacitance box.

V is voltage measured

K_1, K_2, ... K_n are constants obtained in regression tool.

n = 0, 1, 2, ...

Now if we replace the capacitance box and keep the designed sensor, and find the inter electrode voltage values of all combination (28 combinations for an 8 electrode sensor), if we want to find the corresponding capacitance by substituting it in above equation.

Another method that can be implemented to calibrate the sensor is to use two materials with known permittivity. In our system, we took Nylon and PTFE. It is important to keep the humidity(less than 20%) and temperature (between -10 to 20degree Celsius) under control to obtain accurate values of calibration capacitances. The plugs exactly fitted inside the sensors and the inter electrode capacitances with sensor empty and sensor fully filled were carried out.

V.

MAGE RECONSTRUCTION

Capacitance sensor is a soft field sensor. In addition, the number of possible independent measurements is very small compared to the number of pixels required for an acceptable image. These problems make it difficult to reconstruct good quality images. The most popular image reconstruction algorithm [13][14] is called the linear back projection (LBP). It is based on first obtaining the sensitivity distributions (or sensitivity map) for all electrode pairs, and then linearly super imposing the normalized capacitances using the sensitivity maps as the weighting factors to obtain images. It is simple and fast but the image quality is not good, especially for a complex permittivity distribution. To improve image quality, a variety of iterative algorithms have been developed, typically, Yang's method based on Landweber's iteration method. Iterative algorithms can produce better images than the LBP algorithms.

VI.

PPLICATION OF ECT SYSTEM IN PARTICULATE PROCESS MEASUREMENT

ECT system has wide application [15] in industries for measurement of flow regime and solids distribution using ECT, applicable in pneumatic conveyors, gravity flow, fluidized bed etc. Some of the applications of ECT system are described in the following part of the paper.

A . Measurement of flow regime: The flow is of two types: dilute flow and dense flow. In dilute flow in a pipeline, the density in central par is low where as density near walls is high. Thus the porosity distribution is used in stress measurement; this is done for validation of fluid dynamics. If the result is processed by spectrum, the unsteady nature of flow can be found.

B. Measurement of velocity in Pneumatic conveyors: The ECT system is used in monitoring and measuring the flow of particulates in pneumatic conveyors. If the flow regime is dual phase, then system can measure overall flow of system. Based on the capacitance measurement values, concentration and velocity profiles are calculated off line.

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