A Fast Active Differentiator Capacitance Transducer for Electrical Capacitance Tomography

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Abstract - *This paper describes the development of a sensitive and fast transducer for use in electrical capacitance applications. The sensor works by supplying a short voltage pulse to an active differentiator. The sensor has been tested in a twelve electrode configuration mounted around a cylinder of 30 cm.*

Keywords : tomography, capacitance, differentiator, transducer

THE OBJECTIVE

Electrical Capacitance Tomography (ECT) is a young, promising and developing technology with many possible applications. There are recent improvements in the software, particularly the deconvolution routines. However, these must clearly be matched by commensurate developments in the hardware, both the electrodes and the electronics [1,2]. The improvements required are both in sensitivity and speed. An increase in sensitivity will allow more electrodes and will allow the tomographic slice to be thinner. An increase in speed will widen the range of applications. This paper describes the development and testing of a new transducer for use in ECT applications.

THE TRANSDUCER

The transducer has been developed to measure capacitance of the order of 1 fF. It considers the unknown capacitance to be an element of an active differentiator. A constant, negative pulse with well-defined fall and rise times is created by an active differentiator circuit. Its potential fall and rise time are chosen to be 200 ns, and the high potential is kept constant for 1 µs. This pulse is supplied as the input signal for the active differentiator, as shown in Figure 1. At the output of the differentiator a positive and a negative peak result (point B in Figure 1). These peaks are separated using a peak-to-peak detector and are summed by a differential amplifier giving an output potential U_{out}. The sum of these peaks is independent of the baseline potential. Therefore, offsets on these peaks due to a baseline drift have no effect on the measurement.

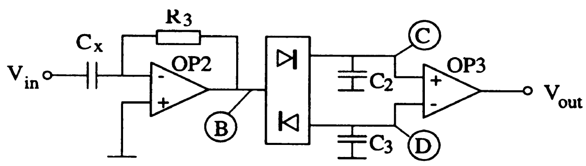

Figure 1: Active differentiator circuit, which forms the output signal proportional to unknown capacitance

The value of the sum of the peaks is determined by a 12-bit Analog Digital Converter. It directly serves as a measure of the unknown capacitance C_x.

$$C_x = \frac{U_{out}}{2\ R_3\left(\Delta U_{in} / \Delta T\ \right)} \qquad (1)$$

The minus-input of the operational amplifier in Figure 1 is virtually grounded. Hence, the potential at the minus-input will not vary, and there is no influence of a parasitic capacitance to ground on the measured value.

After detection, it takes about 9 µs to digitise the signal, to write it to memory, and to reset the peak-to-peak detector to zero for the next measurement. One single capacitance measurement thus takes about 10 µs. Each electrode is equipped with identical input and measurement circuits which are mounted directly on the electrode, without the use of long coaxial cables.

The new system allows for a maximum data acquisition speed of 9000 images./second when applied to a 12 electrode sensor. This high acquisition speed allows for averaging of measurement, or more accurately for digital filtering of the time signals to reduce noise levels before reconstruction of the images.

Due to the large ratio of the nearest electrode capacitance and the opposite electrode, capacitance the active differentiator circuit exhibits thermal memory effects wen operated at high speed. For this reason the nearest electrode capacitance measurement are omitted by using CMOS-switches to reduce the maximum possible capacitance ratio. This gives for a N-electrode system a total number of N(N-3) measurements per image.

In [1], Programmable Gain Amplifiers in combination with differential amplifiers are used to subtract standing capacitance from the measured capacitance to make full use of the measurement range of the Analog Digital Converter. When working with high acquisition speeds the use of these Programmable Gain Amplifiers cannot be recommended due to parasitic effects in the Digital Analog Converters which give amplification factors for the Programmable Gain Amplifiers.

TESTING THE DETECTOR

The new detector has been tested in a twelve electrode system built around a pipe of 30 cm in diameter. The equipment is shown in Figure 2.

Figure 2: The Electrical Capacitance Tomography Set-up

The first tests were made with the pipe empty to establish the reproducibility of the measurements. Each electrode was chosen in turn as the transmitter. A test was then conducted where the average of the five hundred signals on each of the other electrodes was recorded. Each of these tests was repeated five times. The standard deviation of these averages was always less than 2%. Two of the series are compared in Figure 3a, those using electrodes 1 and 2 as the transmitters. They are indistinguishable, the electrode array was, for practical purposes, symmetrical.

The tests were then repeated when the pipe was filled with benzene. This liquid has an appreciable permittivity and a very high resistivity. These results are compared with the empty pipe in Figure 3b.

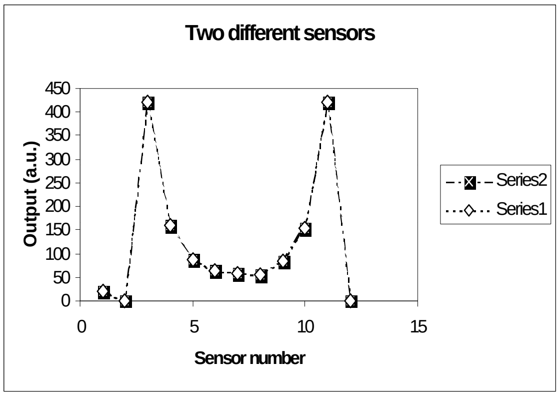

Figure 3a: Output signals from two different sensors

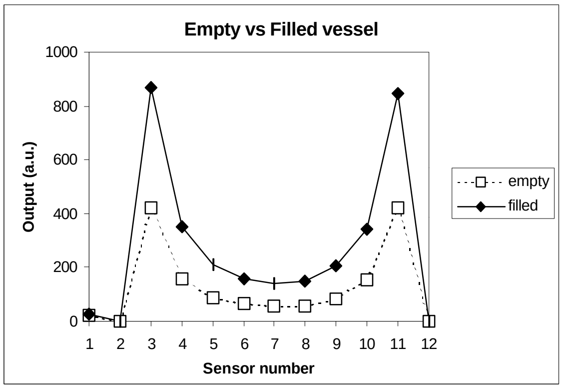

Figure 3b: Output signals for empty and filled vessel

The dielectric has made a clear difference to the signal on each electrode.

The next tests consisted of inserting a phantom obstacle into the empty pipe. The phantom consisted of a glass cylinder, 8 cm in diameter, which was filled with benzene.

Figure 4 shows the reconstruction obtained with the simplest of the reconstruction algorithms, linear back projection. The cylinder is placed in three separate positions.

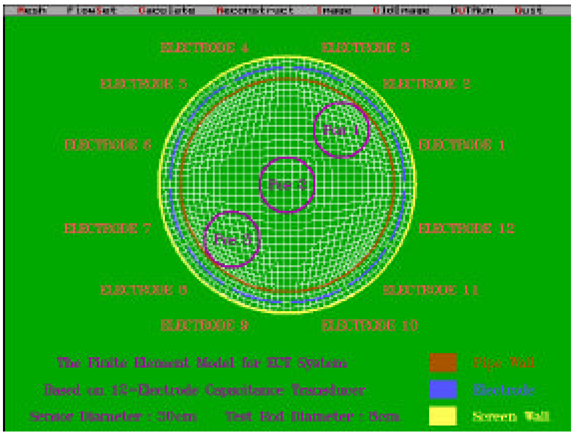

Figure 4a: Test Model

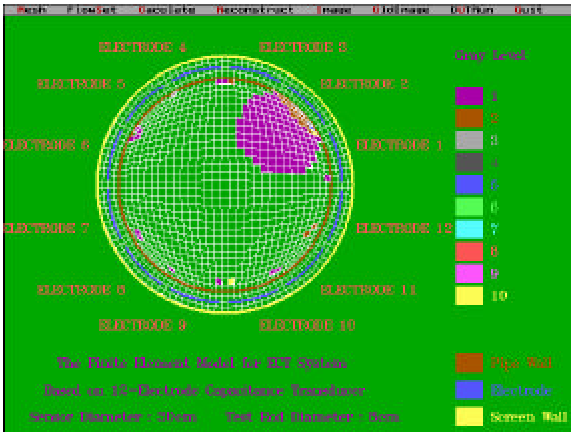

Figure 4b: Reconstructed Pos 1 image based on LBP algorithm

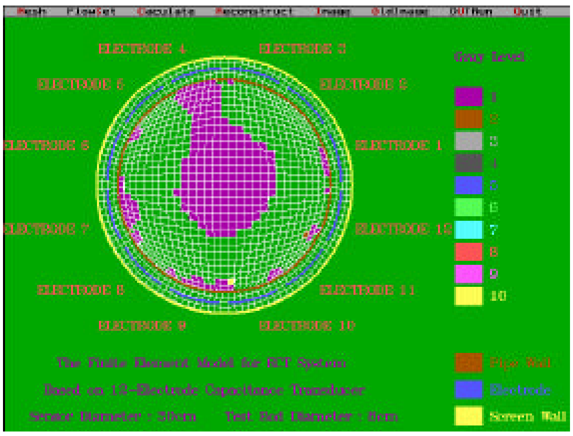

Figure 4c: Reconstructed Pos 2 image based on LBP algorithm

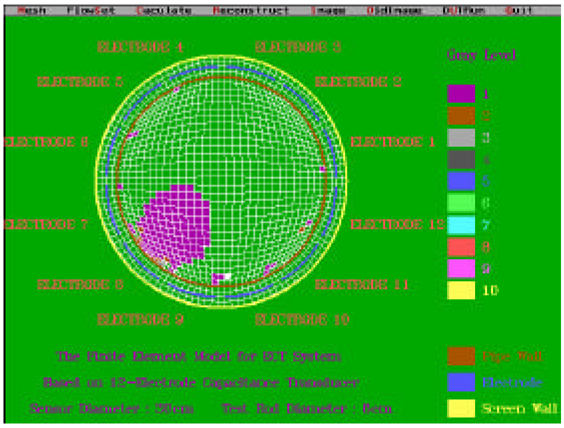

Figure 4c: Reconstructed Pos 3 image based on LBP algorithm

The familiar result is obtained, that is the sensitivity in the centre of the pipe is too low to allow the use of the linear back projection algorithm. The lower level of noise indicated is very propitious for processing this data by an iterative algorithm.

The next series of tests were to evaluate the dynamic response of the system. This was carried out in a tube of 9.5 cm internal diameter. A Teflon cylinder with a relative diameter of 0.3 was dropped through the centre of this tube with an approximate speed of 0.6 m/s. the dynamic response on two opposite electrodes was recorded and is shown in Figure 5. A sampling interval of 2 ms was used which easily recorded this motion.

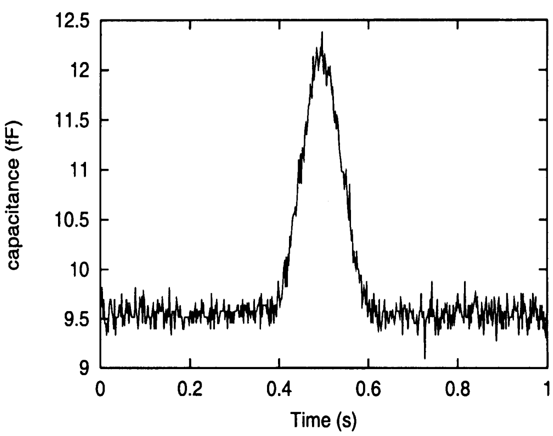

Figure 5: Opposite electrode capacitance signal caused by a falling Teflon cylinder

The system was next installed on a stirred vessel, 30 cm in diameter. In this situation, its practical application could be evaluated. The practical problem is now the large amount of data, which must be handled, and thus compresses. For this purpose a micro-controller circuit was built and implemented. Timing data was set by a serial protocol and programmed in the ”tomo7.pas” program. As much as 10000 pulses at secure intervals up to, 100 µs could be set. Two data sets were generated “snel1ms0-12” and “snelmsb0-12”. In the sets all the data of the local node memories was dumped. Every file of every node contains the full 128 tomogram words, but only the first 12 words are valid. A node memory could hold up to 512 tomograms (128k). On the UNIX system a “Veetest” application was written to display all the valid data of a tomogram set. With an integer value, the controlling node number could be set. In this way, the useful data was separated and recorded and the superfluous data discarded.

The TENTATIVE CONCLUSION is that this sensor system offers considerable advantages over the more traditional charge discharge system.

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