Jurnal Teknologi, 39(D) Dis. 2003: 105–113

INITIAL RESULT ON ELECTRICAL IMPEDANCE TOMOGRAPHY

RUZAIRI ABDUL RAHIM[1], LIEW YI HUEI[2], CHAN KOK SAN[3], PANG JON FEA[4] & LEONG CHAI LEAN[5]

Abstract. Electrical Impedance Tomography (EIT) provides a low-cost measurement instrument for monitoring distributions of electrically conducting materials in pipelines and process vessels. This paper describes the development of an eight electrode EIT hardware system test on an 84mm diameter flow pipe. The measurement of two different water pipe conditions will be compared: water-filled only and water-filled with solid object are presented within the boundary of the measurement.

1.0 INTRODUCTION

Originating from medical imaging, Electrical Impedance Tomography (EIT) is a non-invasive tomography technique that provides alternative solution in fulfilling the needs of both medical field and industrial processes. The general ideas of EIT is to exploit the differences in the passive electrical properties of targeted object and generate tomographic images[1]. The system hardware consists of a number of electrodes mounted encompassing the wall of vessel to make electrical contact with the material inside.

Various combinations of adjacent electrode pairs' voltage in response to small currents injected on certain electrode pairs are measured rapidly and then converted to digital form, as shown in Figure 1. These data are later processed to reconstruct the compositions of conductivity inside the vessel. This can be used to sense changes in the concentration of materials, to detect malfunctions in processes and to allow improved design and operation of process plant.

The theories behind the electrical impedance tomography involved basic electricity theory, which concerned object's behavior under current flow. Governing equations of electricity and magnetism within the object region need to be established.

An electrical current flow in the body does not progress in straight lines, but tends to spread out in all directions. Unlike optical tomography and other collimated imaging modalities, electrical impedance images will not only consist of information relating to the measurement plane, but will also include trivial contributions from the off plane

[1,2,3,4&5] Process Tomography Research Group (PROTOM), Control & Instrumentation Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia 81310 UTM Skudai. ruzairi@fke.utm.my

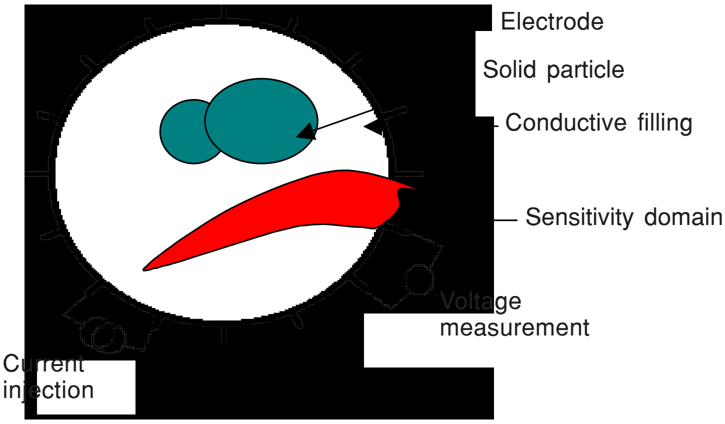

Figure 1 EIT measurement around the pipe

conductivity distribution. Due to these limitations, the reconstructed image will only approximate the true conductivity distribution, in the form of a finite number of piecewise regions or elements. Therefore it is assumed that the electric current is restrained to the two dimensional (2D) plane which coincides with the electrodes. Another simplifying assumption is that the frequency of the applied currents low enough such that the displacement current can be ignored.

The advantages of EIT are:

- low component cost, portable (due to small sensor dimensions and ability to operate remote from host computer).
- scalable (since technique can be applied on vessel cross-sections varies from 10 mm to several meters in diameter).
- fast response (enabling on-line and real-time control).
- unique (provides thus far inaccessible information about internal dynamic processes).
- safe (no ionizing radiation or intense magnetic fields involved).

A severe limitation of EIT is its poor spatial resolution which is related to the number of electrodes used. This is due to the practical difficulties of applying large numbers of electrodes, the associated complexity of the electronics, and the computational difficulties of processing vast quantities of data. The object to be imaged must be conductive enough for the current flow.

2.0 EIT IN INDUSTRIAL APPLICATIONS

The usages of EIT are:

- On-line monitoring of process equipment such as hydraulic conveyors, separators and mixers

- Process control
- Design of process equipment
- Validation of computerized fluid dynamics computer simulation packages
- Laboratory design and educational usage

For example, EIT has been used to image lung functions due to the large differences in the resistivity in lung tissue and air. Other areas of medical research and applications has focused on gastric emptying and detection of malignancies in the body.

In addition, EIT has been used to verify pulp consistency, which can be integrated into a process control loop in the paper manufacturing process [2]. Some of the application studied include imaging of hydro-cyclones and imaging of phase distribution in process vessels. This inexpensive and safe method, therefore, may prove to be an important part of a process control loop in paper production.

3.0 DATA COLLECTION METHODS

The inverse problem involves finding a conductivity distribution, which is consistent with all the measurement data sets and any predefined conditions. Theoretically, increasing the number of independent measurements enhance the reconstruction quality. This improvement in spatial resolution is also related to measurement accuracy and noise.

There are several strategies of data collection that have been used in previous research.

3.1 Neighboring Method

As featured in Figure 2 current is applied through two neighboring electrodes and voltage from all other successive pairs of adjacent electrodes are measured. Despite

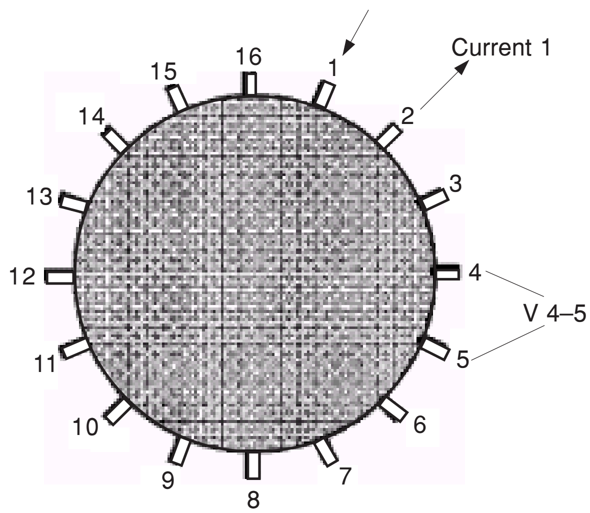

Figure 2 Neighbouring method with 16 electrodes

non-uniform current and low current density, the method does not yield good sensitivity in the middle of the flow pipe [3].

3.2 Opposite Method

Current is injected through diametrically opposed electrodes while the voltage reference electrodes were adjacent to the current-injecting electrodes, as shown in Figure 3. At the instant, all the voltages are measured with respect to the electrodes. For the next data set, current is switched to the next pairs of electrodes in clockwise direction. This method has more uniform current density and therefore good sensitivity [3].

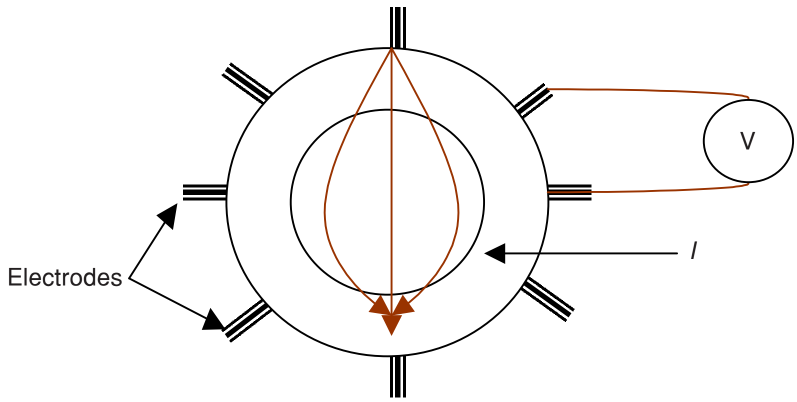

Figure 3 Opposite method

3.3 Adaptive Method

The desired current distribution is obtained by injecting a current of appropriate magnitude through all the electrodes simultaneously. The sensitivity of the desired zone is measured and the current keep changing magnitude until the optimal current is reached. Although more complicated, this method gives the best distinguishability and is the most versatile method of data collection [3].

4.0 EIT HARDWARE

Figure 4 shows a real hardware block diagram for EIT system. The electrodes are the basic element in the system. These electrodes have two functions. First, the electrodes convert the electric current from the circuit into ionic current in an electrolyte. Secondly, the electrodes act as measurement instrument for data acquiring. The sine wave generator provides waveform to voltage control current source (VCCS) to convert voltage into desired current. The instrument amplifier will send the measured voltage to signal conditioning block for further adjustment before feeding into DAS processing.

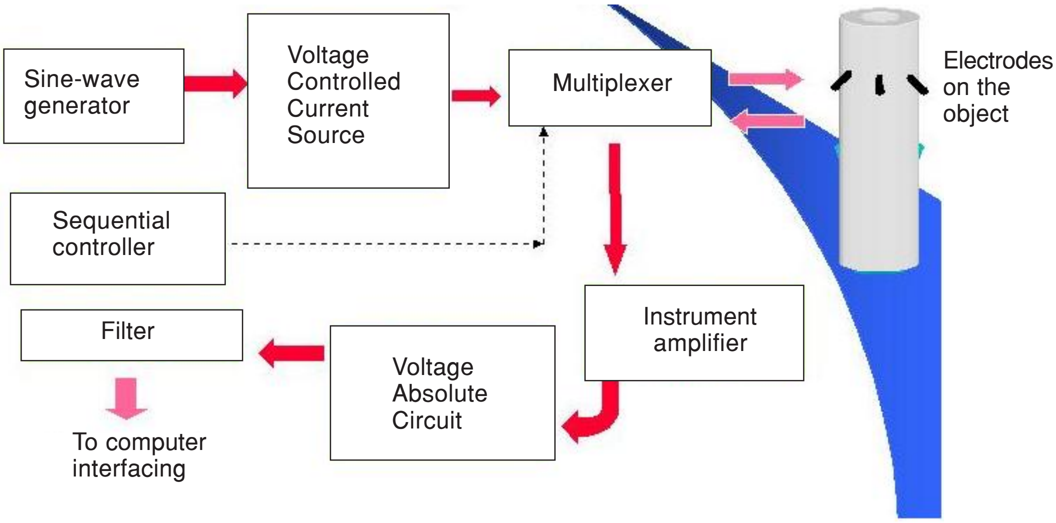

Figure 4 Block diagram of an EIT hardware system

4.1 Electrode Design

The material chosen for the electrode design is brass metal. Brass is a primary alloy of copper and zinc. It is composed of nearly 60% copper, 40% zinc and small percentages of other material. The composition is non-standardized and therefore the brass materials found in market slightly differ in colour and stiffness. The reasons using brass is that it is a low cost material with high corrosion resistant and able to withstand high temperature. Also, the impedance is lower than the other alloy as the of electrical frequency increases.

Figure 5 shows the electrode fabrication of electrode sensors on the pipe wall. The electrode is 3 mm in diameter with a length of 30 mm. The electrode is permanently sealed on the pipe-wall. Exact holes are made on the wall for placing the electrodes. Some epoxy resin is applied around the interface between the electrodes and the pipe

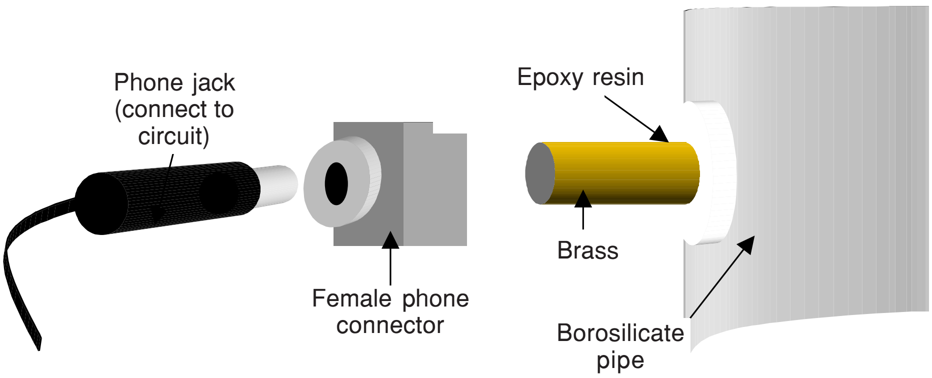

Figure 5 Electrode fabrication

wall. This is to ensure that the position of the electrodes will not move and enclose any space that leads to electrolyte leakage.

For convenience of attaching and detaching, a phone jack is used to connect the coaxial cable routed from the circuit towards the brass electrodes.

Eight electrodes have been embedded to a borosilicate type pipe. The advantages of using this type of pipe is for convenience of observation of the object inside the transparent glass pipe.

5.0 RESULTS AND DISCUSSIONS

5.1 Results

Analysis is carried out with different pipe conditions:

- The pipe is filled with static water only
- The pipe is filled with static water, and a 30 mm diameter PVC pipe is dropped into the water. The pipe wall is about 2 mm.

For each of the conditions, twenty independent measurements have been made

Table 1 Measured data of condition 1

No.	Injection electrode pair	Measurement electrode pair	Value (V)
1	1-2	3-4	4.24
2	1-2	5-4	1.79
3	1-2	5-6	2.1
4	1-2	7-6	9.5
5	1-2	7-8	6.96
6	3-2	7-8	4.16
7	3-2	7-6	4.2
8	3-2	5-6	2.12
9	3-2	5-4	2.6
10	3-2	1-8	6.08
11	3-4	1-8	2.28
12	3-4	7-8	7.32
13	3-4	7-6	3.12
14	3-4	5-6	2.04
15	5-4	7-6	12.1
16	5-4	7-8	9.07
17	5-4	1-8	1.7
18	5-6	1-8	1.8
19	5-6	7-8	3.9
20	7-6	1-8	11.3

Table 2 Measured data of condition 2

No.	Injection electrode pair	Measurement electrode pair	Value (V)
1	1-2	3-4	4.22
2	1-2	5-4	1.6
3	1-2	5-6	2.2
4	1-2	7-6	9.5
5	1-2	7-8	6.7
6	3-2	7-8	4.2
7	3-2	7-6	4.4
8	3-2	5-6	3
9	3-2	5-4	2.4
10	3-2	1-8	6.1
11	3-4	1-8	2.2
12	3-4	7-8	7.5
13	3-4	7-6	3
14	3-4	5-6	2.3
15	5-4	7-6	12.02
16	5-4	7-8	10
17	5-4	1-8	1.7
18	5-6	1-8	1.79
19	5-6	7-8	3.9
20	7-6	1-8	10.7

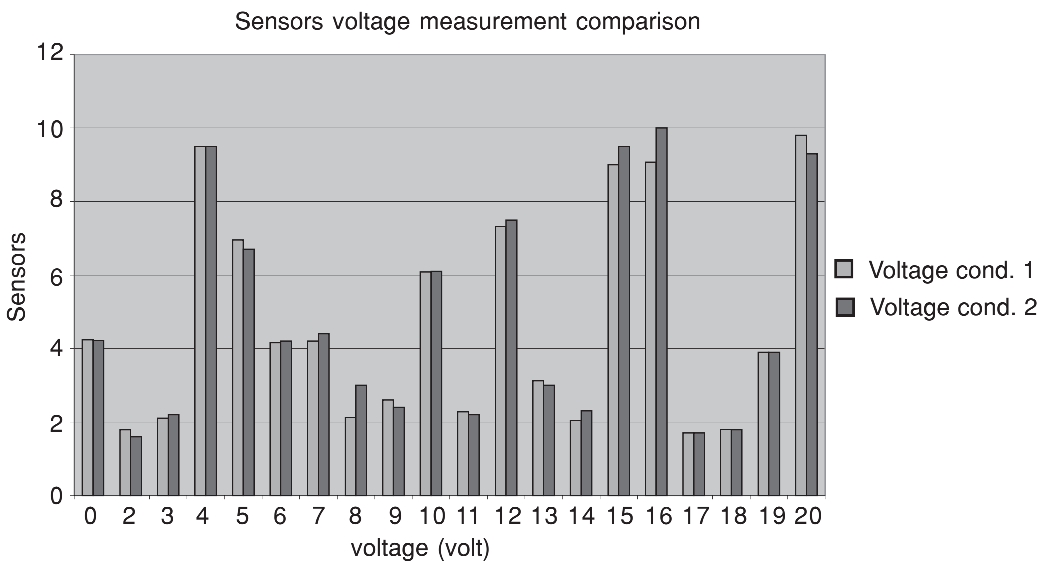

Figure 6 Graph of two sets of measurements

manually. That is, for each independent measurement, a microcontroller is assigned to perform a single measurement task. The outputs of the measurements are displayed by oscilloscope. By reading the RMS values, the result is tabulated as in Table 1 and 2. A bar graph (Figure 6) is used to compare the voltage output at different conditions. The results show that there is a slight difference between the two conditions.

From observation, once the pipe reaches or approaches the electrodes, the outputs show the largest voltage difference. Presumably, the obtained voltage of the first condition is lower than the second condition. From experiments, some of the voltage becomes lower or remain the same. This might be due to offset errors or some of the sensor position is different from the default position. Some of the sensors also becomes insensitive until the pipe comes very close to the electrodes.

6.0 DISCUSSION

The EIT system is a very sensitive system. In a perfect system, the measured voltage should be equally weighted. Due to construction errors, the measurements become imbalanced. If the electrodes' head is pushed further out of the vessel wall, it might become a dominant 'disturbance'. The measurement will thus lead to severe errors. On the other hand, the introduction of multiplexer in a measurement leads to distorted voltage shape, as the impedance reduced. The signal is not pure sinusoidal at the end of the outputs.

REFERENCES

[1] Metheral, P. 1998. "*Three Dimensional Electrical Impedance Tomography of the Human Thorax*." University of Sheffield: Ph.D. Thesis

[2] Williams, R. A., and Beck. 1995. *Process Tomography – Principles, Techniques and Application*. Oxford: Butterworth-Heinemman Ltd.

[3] Szczepanik, Z., and Z. Rucki. 2000. "Frequency Analysis of Electrical Impedance Tomography System". *IEEE Transaction On Instrumentation and Measurement*. 49: 4.