FAST DATA ACQUISITION SYSTEM FOR IMPEDANCE TOMOGRAPHY

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Abstract: In the paper concept of the measurement (based on the sampling of potential differences during one period of the measuring signal) for impedance tomography data acquisition is described. Proposal of elimination of influence of dc electrochemical potential on data acquisition system is given in the paper as well. Thus suggested method enables increasing the rate of measurement. Results of experiments and image reconstructions confirming authors concept are shown.
Keywords: impedance tomography, data acquisition, electrochemical impedance.

1 INTRODUCTION

In the paper problems of the increasing of rate of measurements for the impedance tomography [1] are considered. The objects of impedance tomography (often called resistance tomography) imaging are of ionic conductivity nature (electrolyte solutions with gas cavities or solid impurities, solids filled with electrolyte solutions etc.). High rate of the measurements enables real time dynamic processes tracing e.g. mixing of liquids, solids and gases dissolving, transport of the water containing gas cavities and impurities, migration of the water in solids (wood, concrete etc.), liquid and foam transport in the foaming columns and so on.

The ability to perform real-time tomography at rates of tens images per second has been achieved by one of electrical tomography techniques - capacitance tomography [2]. Unfortunately this achievement can not be directly transferred to the impedance tomography. Methods used by capacitance tomography are not useful then, due to different electrical properties of the investigated object (dielectrics rather than ionic conductors). In the case of resistance tomography, problems of resistivity distribution measurement are related to the electrochemical phenomena, arising at the electron conductor (sensor electrodes) and ionic conductor (investigated object) interface. As a result at electrodes surface arises new structure. Its properties depend on the electrodes, ionic conductor and its concentration etc. From the electrical point of view these phenomena introduce to the measuring network additional impedances (Z_1, Z_2) as well as electrochemical potentials (E_1, E_2, E_3, E_4 - Fig. 1).
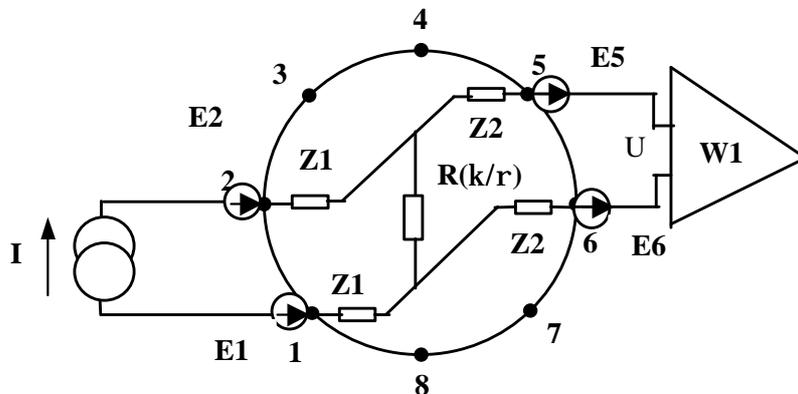

Fig.1. Four-electrode equivalent electrical model of the impedance sensor connected to the measuring system, where: Z1, Z2 - interfacial impedances, R(/) – object, E1,E2,E5,E6 – electrochemical potentials, U - measured voltage between electrodes, I – current driving the electrodes, W1 –differential amplifier

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The values of the impedances and potentials shown in the Fig. 1, depend on the intensity of the processes forming the dynamic equilibrium between ionic and electron conductors. Only in the case of the identity of the electrodes, all electrochemical impedances and potentials would be exactly the same. It is not a case in practise, as there are many differences of mechanical, electrical and chemical nature.

The question of the impedance of the sensor electrodes-object interface is rarely discussed in the professional papers. Only few papers in the field of medical application of impedance tomography [3], [4] deal with the interfacial impedance problem. However, the electrochemical potentials at this interface are not noticed at all. The same goes for the industrial applications of the impedance tomography [5],[6].

In practise, to minimise the interfacial impedance effect, the four-electrode method is commonly used. However, proper selection of the measuring signal frequency is substantially important as well, as the authors have reported in [7].

2 MEASURING PROBLEMS RESULTING FROM ELECTROCHEMICAL POTENTIALS

The electrochemical potentials at sensor electrodes produce step excitation (apart from the harmonic signal excitation) of the measuring transducer, each time the new pair of electrodes is connected to the acquisition system. As the electrochemical potentials depend on individual properties of each electrode, this step excitation varies during electrode pairs multiplexing, causing the operation point of the input amplifier (W_1 in Fig. 1) variation. This steps may even exceed the linear range of operation of the amplifier. It is illustrated in Fig. 2 showing superposition of measured harmonic signal and transient resulting from the electrochemical potential step. Obtaining the steady state requires to wait many measuring signal periods (more than 20 s in the case shown in the Fig. 2). This is particularly inconvenient in the case of real time impedance tomography.
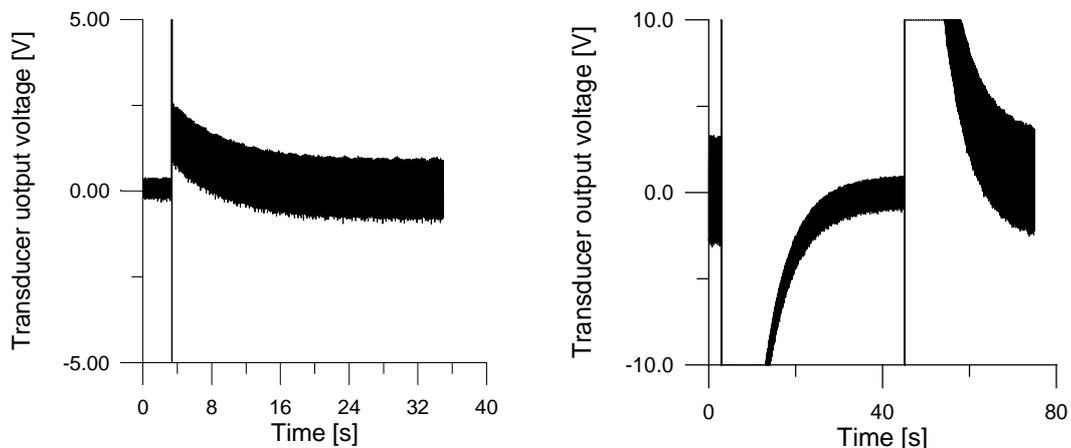
Fig. 2 Examples of two transients resulting from dc bias at amplifier input

One can avoid operation point variation, eliminating sensor electrodes multiplexing. A proposal of problem solution is presented in the next chapter.

3 METHOD OF MEASUREMENT

Fig. 3 shows schematic diagram of measuring transducer used in the impedance tomography data acquisition system. Input circuit of the transducer consists of the differential amplifiers permanently connected to the sensor electrodes. Application of isolating amplifiers e.g. AD 202 enables complete elimination of the dc potentials (caused by the electrochemical phenomena) at amplifiers outputs. Permanent connection and isolation allows the rate of measurement to be considerably increased. Very fast solution is simultaneous processing of all channels, thought this requires several converters. It should be noticed that multiplexing of driving electrodes does not influence the operation point of the input amplifiers.

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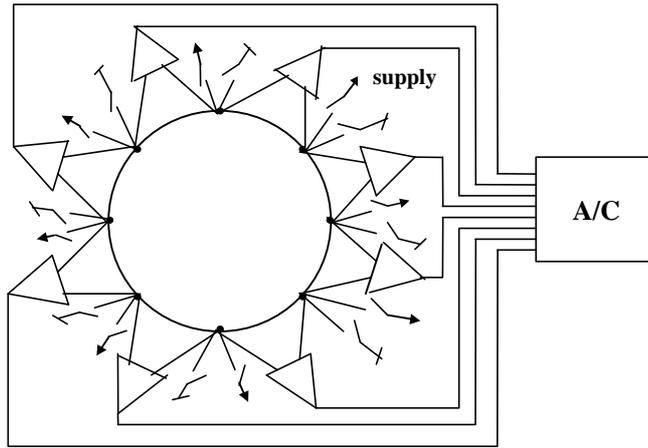Vienna, AUSTRIA, 2000, September 25-28

Fig. 3 Schematic diagram of the measuring transducer for the impedance tomography

The next increase of rate of measurement is possible in the case of sampling of measuring signal within time no longer than one signal period T - Fig. 4. The authors have been proved [8] that even as short sampling time as a half of signal period, enables determination the root mean square value. It should be underline that there is no necessity to sample synchronously with measuring signal.
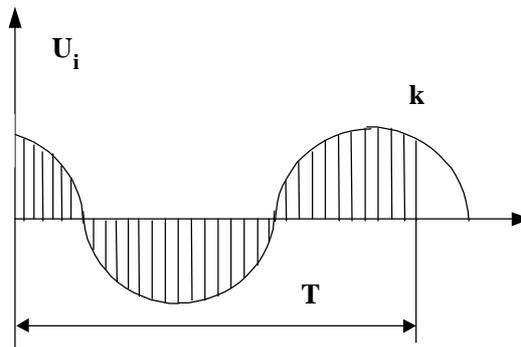

Fig. 4. Illustration of the voltage average value measurement by signal sampling during one
period of signal, where T - measuring signal period, k - number of samples,
U_i - samples

In practise it is better to sample full period, because then residual dc biases (resulting for example from transducer offsets) can be easily calculated. In general, software separation of dc and ac components seems better solution than hardware one.

In the experiment described in the next chapter following formulas have been used to determine signal parameters:

dc bias was calculated on the basis of eq. 1:

$$U_{mean} = \frac{1}{k}\sum_{i=1}^{k} u_i \tag{1}$$

a half signal period mean was calculated as:

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$$U^{*}_{mean} = \frac{1}{k}\sum_{i=1}^{k}|u_i| \qquad (2)$$

root mean square value was calculated from eq. 3:

$$U_{RMS} = \left(U^{*}_{mean} - U_{mean}\right)\cdot \boldsymbol{p} \left/\left(2\sqrt{2}\right)\right. \qquad (3)$$

where: k - number of samples
Eq. 3 allows the residual dc bias to be cancelled out. An assumption of undistorted harmonic signal has been made. At sufficiently high number of samples the RMS estimation is quite satisfactory.

4   EXPERIMENT

To verify concept of measurement by signal sampling during one period and to evaluate its usefulness for image reconstruction, some experiments have been carried out. Full measuring cycle giving complete set of the results enabling image reconstruction, has been done. 16 - electrodes sensor of 80 mm diameter filled with KCl solution of 0.05 M concentration was used. A cylinder made of plexi of 25 mm diameter was put near the sensor boundary. Frequency of the measuring signal was 20 Hz. Potential differences at the electrodes were measured using sampling converter TAD01 (Convert, Poland). Sampling frequency was 2000 Hz; this means 100 samples per signal period. Examples of sampled results are shown in Fig. 5 and calculated rms values are given in the Tab. 1. For comparison the same potentials were measured using HP 34401A multimeter.
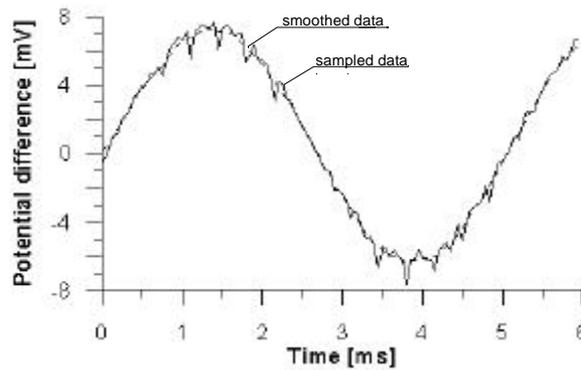

Fig. 5 Example of potential difference measured by signal sampling. Some smoothing procedures are necessary to minimise transducer noises.

Both sets of results were used to obtain image reconstruction using the same LBP algorithm worked out be the authors [9]. Obtained images are shown in Fig. 6. Similarity of both should be noticed.

Tab. 1 Comparison of the potential differences at measuring electrodes, measured using HP 34401A and sampling by plug-in card.

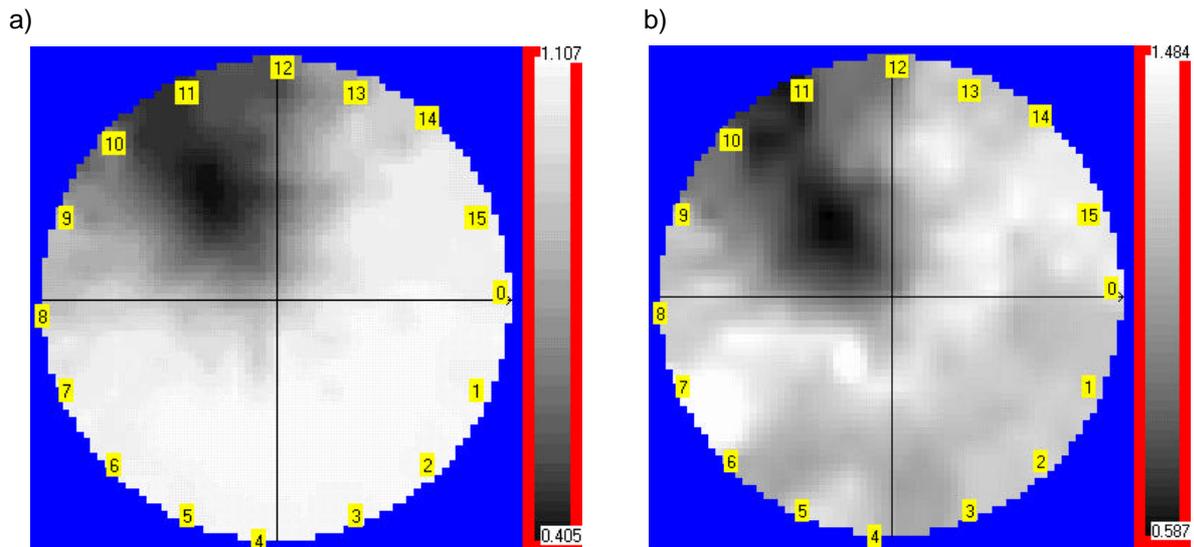| Driving Electrods	Measurig electrodes	Potential by sampling	Potential by HP 34401A
4-5	6-7	14.87	11.696
4-5	7-8	4.63	4.881
4-5	8-9	2.75	2.716
4-5	9-10	1.93	1.932
4-5	10-11	2.00	2.058
4-5	11-12	4.67	4.272
4-5	12-13	2.67	3.195
4-5	13-14	1.44	1.585
4-5	14-15	1.74	1.560
4-5	15-16	1.82	2.093
4-5	16-1	2.32	2.967
4-5	1-2	6.18	5.114
4-5	2-3	13.01	12.117

a)

b)

Fig. 6 Results of image reconstruction obtained using the same LBP algorithm
a) data measured usung HP 34401A
b) data measured by sampling

5   CONCLUSIONS

Measurement of the potential differences between sensor electrodes by sampling during one period of the measuring signal enables considerable reduction of overall data acquisition time. However it should be noticed, that this technique may be used only when dc electrochemical potentials do not influence the operation point of the input of measuring transducer. This in turn means the necessity of permanent connection of the amplifiers to all electrodes pairs, in order to avoid electrodes multiplexing.

   Short data acquisition time will enable real time impedance tomography and tracing the dynamic of many processes.

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