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FAST IMPEDANCE TOMOGRAPHY

Zdzislaw Szczepanik, Zbigniew Rucki

Faculty of Electronics, Wroclaw University of Technology, Wroclaw, Poland

Abstract – In the paper, the problems limiting the rate of data acquisition in the impedance tomography system are considered. Designed by the authors impedance tomography system is described, its performance and results of investigations carried out using this system are also given.

Keywords: impedance tomography, fast measurement, transients

1. INTRODUCTION

Investigation of the distribution of electrical resistivity in the bulk of the object requires sweeping the object structure at different angles [1] using electrical energy. In practice, the source of ac exciting signal and measuring converter must be relocated in relation to the object border – usually by switching to successive electrodes of the sensor. Impedance tomography requires the measuring electrodes to be in galvanic contact with the object. The measured objects are of ionic conduction nature (water electrolyte solutions etc.) and in the contact with the electron conductor (metal electrodes) arise some electrochemical phenomena at surfaces of the electrodes. In general, because of these phenomena, in the measuring circuit appear electrical impedances and the sources of dc potentials (denoted in the Fig. 1 by Z and E, respectively). Electrochemical impedances and sensor's and measuring converter's capacitances are the reason that, in fact, the impedance of the object-sensor system, rather than the resistance is measured [2]. In turn, dc electrochemical potentials are additional (to the ac exciting source) sources exciting measuring converter. Impedances (resistances and capacitances) of the measuring system are the reason of transients, when necessary switchings are made. Problem of the transients is of great importance, when they become comparable with the time of measurement. This is a case when the time of measurement, as well as interval between successive measurements should be very short to increase the rate of measurements. Such a measurements are very desirable when the objects of high dynamic are studied.

The authors have implemented the method of fast data acquisition, to enable real-time impedance tomography. One of the distinctive features of the method, is determination of the root mean square (rms) value of harmonic signal, during its one period - several samples are then taken and rms value is calculated numerically [3].

2. TRANSIENTS IN THE IMPEDANCE TOMOGRAPHY SYSTEMS

The technique of measurement used in the tomography ("seeing" the object at different angles) requires continuous switching both the source of excitation and measuring converter between successive pairs of the sensor's electrodes. In the impedance tomography, four-electrode technique is commonly used, and always two pairs of the electrodes are used simultaneously, during each single measurement – Fig. 1. Very often, first of all, the source is connected to one pair (exciting electrodes - 1,2 in the Fig. 1) and then the measuring converter is successively connected to all other pairs (e.g. electrodes 8,9 in the Fig. 1). Every switching performed in the circuits containing elements accumulating electric energy, must result in the transients. In the impedance tomography system the accumulating elements are the parasitic capacitances of the measuring system and capacitances caused by electrochemical phenomena at the electrodes-object interface. The last capacitances are of higher values and in practice dominantly determine time of transients.

In any circuit containing the elements accumulating electric energy, the response $u(t)$ (say voltage drop at some resistance, that is current) to the source switching, must consist of the steady-state $u_{ss}(t)$ and transient $u_t(t)$) components – equation (1).

$$u(t) = u_{ss}(t) + u_t(t) \tag{1}$$

Transients decay exponentially [4], depending on the time constant T, determined by the circuit's resistances and the capacitances as is given in equation (2).

$$u(t) = U_m k \left[\sin(\omega t + \varphi) - \sin(\varphi) e^{-\frac{t}{T}} \right] \tag{2}$$

where $U_m k \sin(\omega t + \varphi)$ is steady-state component, $U_m k \sin(\varphi) e^{-\frac{t}{T}}$ is transient component, k is coefficient depending on circuit's impedances, T is time constant of the measuring circuit and φ is a phase shift in the circuit.

Fig. 2 illustrates processes (including transients) in the circuits containing elements accumulating electric energy (impedance circuits). Transient component $u_t(t)$ is shown by the curve d). Complete response $u(t) = u_{ss}(t) + u_t(t)$ is shown by the curve c). Curve a) shows the reference (exciting source signal) $u(t) = U_m sin(\omega t)$. Curve b) shows steady-state $u_{ss}(t)$, the $u(t)$ tends to, when $u_t(t)$ decay.

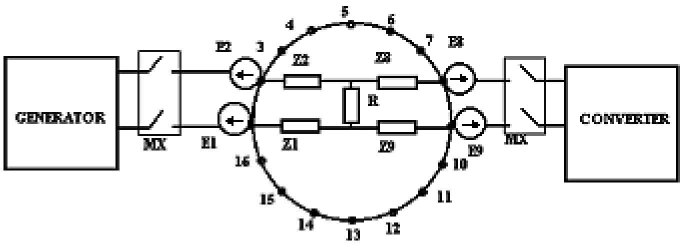

Fig. 1. Idea of impedance tomography system

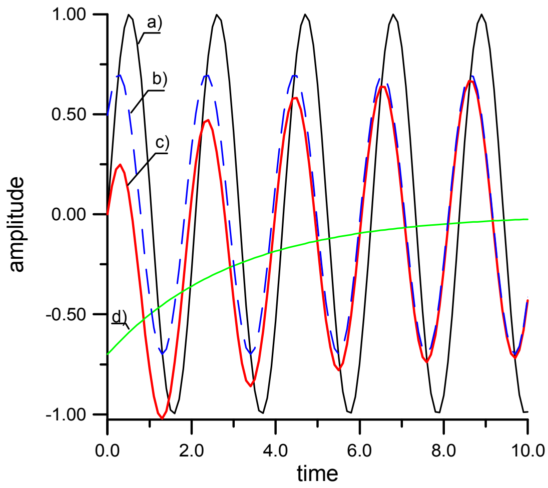

Fig. 2. Illustration of transient and steady-state curves in the impedance circuit

On the basis of equation (2) one should conclude that, the measurement of the signal value (e.g. true root mean square value) is correct only when transient decay (practically after few time constant). Therefore, limitation of the transients in the measuring system is required to increase the rate of measurements, and the authors have paid attention to obtain such a result. As a result of these efforts, the switching operations have been moved from high impedance circuits to the low impedance ones [5]. In the designed impedance tomography system, measuring amplifiers of high input impedances are permanently connected to all pairs of the electrodes. Switching of A/D converter is moved out to the outputs of these amplifiers (of low output impedances).

3. INPUT AMPLIFIER

Input stage of the measuring amplifier being in direct contact with the electrodes of the sensor, should enable correct measurement of the potential difference at the electrodes. Potential difference is measured accurately when o current is driven from the measured object. High input impedance amplifier fulfils this condition. One should keep in mind, that input of the amplifier may also be also influenced by dc step excitations. These excitations result from switching the amplifier to the electrodes that have different electrochemical potentials. It should be noticed, that dc electrochemical potentials may possibly be of the order of 100 mV, that is much higher than ac measuring signal (usually of the order of several mV). An example of dc electrochemical potentials of different pairs of the electrodes is shown in the Fig. 3.

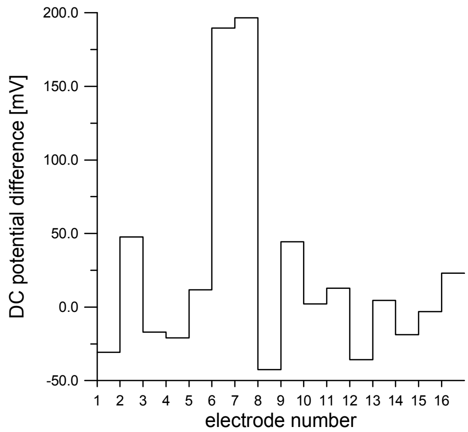

Fig. 3. DC electrochemical potentials between neighbouring electrodes of the impedance sensor

This is why amplification of the input stage of the amplifier should be relatively low – to not exceed linear range of amplifier's operation. Fig. 4 gives an example of such a case. As the dc potentials are the disturbing ones, they may and should be easily eliminated e.g. using isolating amplifiers or just by blocking capacitor.

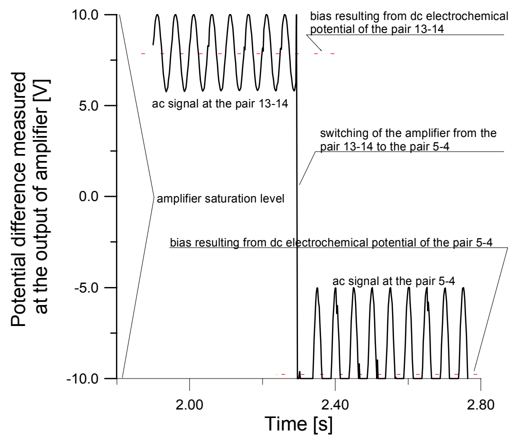

Fig. 4. Variation of the operation point of the input amplifier during electrodes multiplexing.

Fig. 5 shows scheme of measuring amplifier that is used in the impedance tomography system. Amplifier consists of voltage followers directly connected to the sensor's electrodes, differential amplifier and non-differential amplifier as the last stage. Isolation of dc component is realized by buffering capacitor C_1 placed directly ahead of the last amplifier. To each pair of the electrodes is permanently connected such a amplifying/isolating set.

Very important factor is also careful selection of the frequency of measuring signal. There is rather narrow frequency band, for which potential difference is a measure of the object resistance. This results from complex four-terminal model of the impedance tomography system [2].

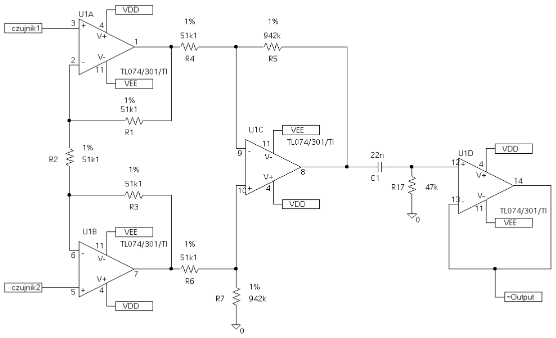

Fig. 5. Input amplifier

4. IMPEDANCE TOMOGRAPHY SYSTEM

The impedance tomography system worked by the authors (shown in the Fig. 7), consists of a set of measuring amplifiers (AMP), a source of sinusoidal current (SIN CURRENT SOURCE), a set of switching keys (MX) used to switch the current source, personal computer and data acquisition plug-in card (PCI). System can be used with impedance tomography sensors (SENSORS) containing up to 32 electrodes. D/A converter (build in the plug-in card) produces measuring signal of frequency 2000 Hz. The signal consists of 12 steps per period. Voltage signal is then converted to the current one by external source of sinusoidal current (SIN CURRENT SOURCE). The current can be set to required value from software menu. Current source is multiplexed to the pairs of the electrodes by a set of the keys (MX), controlled by the digital I/O outputs of the plug-in card. The measuring amplifiers (AMP) are permanently connected to each pair of the electrodes, and on board A/D converter is multiplexed at the outputs of these amplifiers. For that purpose, 16-channel multiplexer (SW) (also on board) is used.

5. MEASUREMENT AND IMAGE RECONSTRUCTION

In the case of 16-electrode sensor, at one current source sition, 13 potential differences are always measured. This results from the fact, that the differences are measured between all neighbouring electrodes (with the exception of these pairs, where the supplying ones would be involved). Thus reconstruction of one image requires (16 x 13)/2 =104 independent measurements to be completed. By one measurement, determination of rms value of the potential difference at one pair of the electrodes is meant. Every determination of rms value is carried out during one period of measuring signal. Sampling technique is employed to measure successive instantaneous values u_i of the potential difference, and rms value U_{rms} is calculated numerically according to equation (3)

$$U_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} u_i^2} \tag{3}$$

where i is current number of the sample and n is total number of the samples. The samples u_i are taken interchangeably with generation of the excitation (one step of excitation then one sample of the potential difference and so on). Thus, in the realised tomography system, 12 samples per period were taken. Complete set of 104 U_{rms} values is used by software to reconstruct one image. Because the current supplying the electrodes is constant and known, the U_{rms} values are proportional to the object's resistances, and may be directly used to determine distribution of the resistance within the space of the object, that is to perform image reconstruction. To determine the distribution of the resistance, the cross-section of the sensor is divided into 132 squares – Fig. 6.

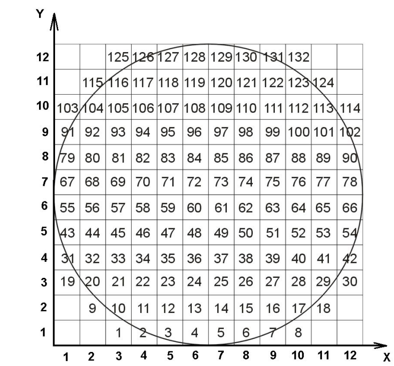

Fig. 6. Illustration of division of the sensor's cross-section into squares used by image reconstruction algorithm

Typical Linear Back Projection algorithm is used for determination of the resistances of the squares. One complete image consists of the values calculated for all squares. The values of the resistances are then converted into gray scale and displayed.

At present 5 images per second has been obtained. This value is actually limited by the maximum rate of plug-in card used.Some images obtained using the system are shown in the Fig. 8.

6. CONCLUSIONS

The procedure of minimising the transients by moving the switching operations from high impedance to low impedance circuit, has enabled lowering of total time of measurement. Also the method of determination of rms value during one period of measuring signal has permitted fast data acquisition. Both methods have been practically verified in the designed impedance tomography system.

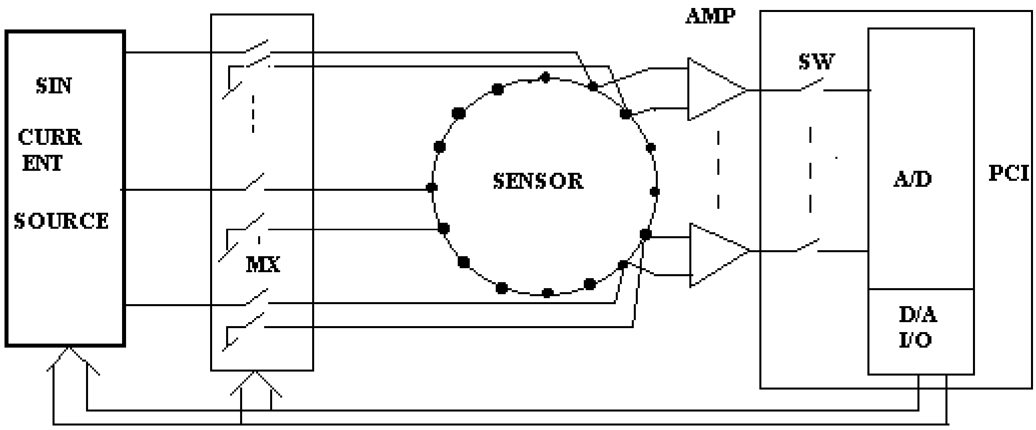

Fig. 7. Scheme of measuring system

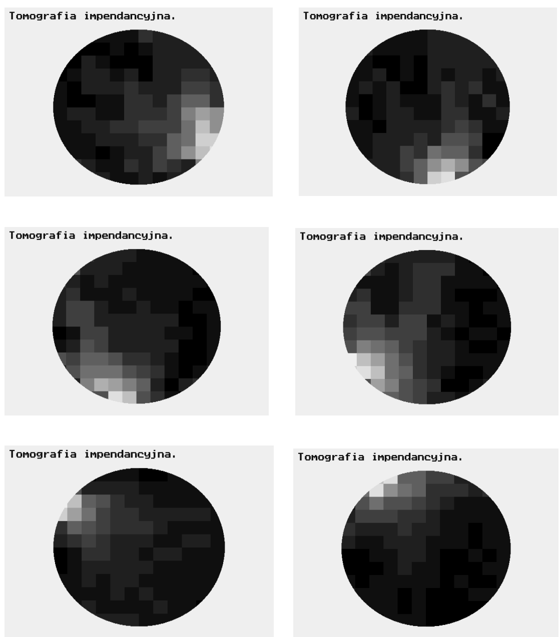

Fig. 8. Examples of the images obtained using described system. An object rotating at the sensor circumference is shown. Successive images are reconstructed at 0.2 s intervals.

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Authors: Zdzislaw Szczepanik, Zbigniew Rucki, Division of Measurement and Measuring ystems, Faculty of electronics, Wroclaw University of Technology, ul. B. Prus 53/55, 50-317 Wroclaw, Poland, tel. +48 71 320 62 45, fax +48 71 327 77 27, e-mail:szczepanik@zwmsp.pwr.wroc.pl