PHANTOM OF THE BIOLOGICAL LAYERED STRUCTURE FOR AN EXPERIMENTAL EVALUATION OF THE MEASUREMENT METHOD

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Abstract: A phantom of a layered structure is presented in the paper. It is used to validate of recently developed algorithm for skin burns determination [1]. It allows estimating of electrical and geometrical parameters of the burned skin. Two different phantoms are discussed in the paper. Also, a measurement stand developed for measuring a layered structure of different geometry is presented.

Introduction

The aim of the study is to develop the method of identification of burned skin parameters, which can be at the first attempt, considered as a layered structure. An increased complexity of the structure, as compared to homogenous one, requires finding several parameters, which describe its electrical and geometrical parameters [2]. This is realized by means of special configurations of electrodes, with the possibility to make many independent measurements [1,3]. A stand for experimental verification of theoretical data is presented in the paper. Impedance of a layered structure has been calculated for a multi-ring measurement probe.

Methods

Theory

Theoretical studies show that the identification of layered structure properties is possible by measurements done on its surface. However, it demands of using appropriate probe [1,3]. A number of independent measurements has to be increased as a result of increased number of searched parameters. A potential distribution inside the layered structure associated with current flowing between annular (ring) electrodes has been obtained using a Finite Element Method (FEM). FEM model containing two layers of different conductivity of appropriate dimensions has been developed. More details are given in Figure 1. Electric field potential distribution for a quasi-static case, created by a ring electrode, in a layered structure may be described by triple integral equations [4] but here FEM approach is used.

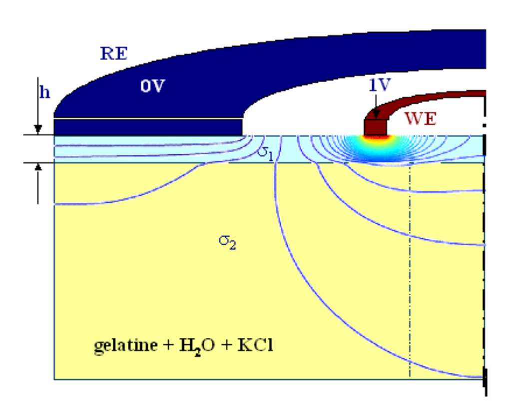

Figure 1: Potential distribution in two - layered structure (cross-section), RE – reference electrode, WE – working electrode

Experimental stand consists of impedance analyser, enlarged probe model, and tank containing solution of KCl and cylinder of gelatine placed on movable disk. Several types of probes have been examined; among them one of annular construction (Fig. 2).

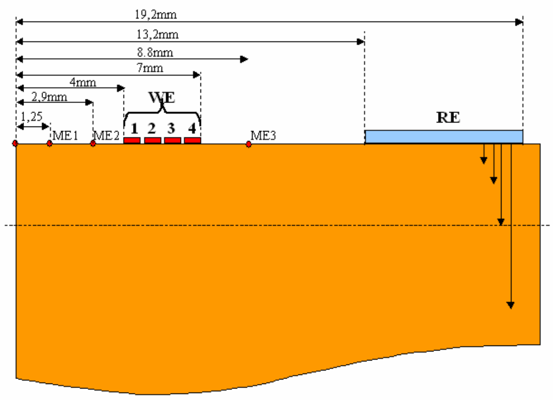

Figure 2: Scheme of the examined probe, WE consists of 4 rings, ME1, ME2, ME3 – measuring electrodes

The excitation current is forced to flow between WE and RE electrodes. WE electrode is a multi-ring one. It allows changing the position of WE electrode in respect to RE one, or changing its width.

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To calculate the resistance for different conductivity and thickness of the top layer and an assumed conductivity of the bottom layer the Laplace equation has been solved. However, this equation external layer of has been solved for a mixed boundary conditions, i.e. it is assumed that WE and RE elctrodes are equipotential having potentials 1 V and 0 V, respectively. The current flowing between electrodes has been calculated after determination of potential distribution. Finnaly, the potential distribution has been adjusted to obtain a desired value of current. Only a sector of the 3-D model may be considered as for the ring electrode. 3-D problem can be reduced to the 2-D case however, it demands an appropriate FEM solver for cylindrical coordinates system. Also infinite dimension of underlying tissue is assumed, what makes calculations more adequate to real conditions. A boundary condition of infinite extension of underlying medium has been obtained by assuming that the external FEM layer has different conductivity. This conductivity has been so chosen that the total resistance of the medium equals to that extending to the infinity. Resistance measured using the probe have been calculated using realistic data needed for evaluation of the proposed method for a two layer case. To evidence the nonuniform current density distribution FEM mesh contains non-uniform distribution of elements. Complexity of the model depends on analysed case. The IDEAS software has been used as one of possible and very powerful tool. An influence of WE electrode width on potential distribution has been examined for a specific depth *h* of burnt tissue and as a function of conductivity ratio σ_2/σ_1 (Fig. 3).

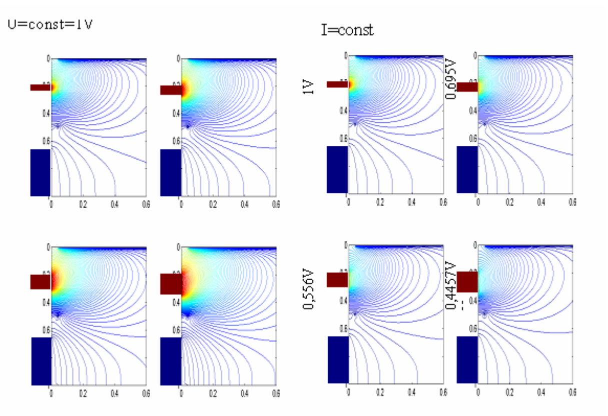

Figure 3: The potential distribution in the medium (as obtained by FE method) created by current flowing between WE and RE electrodes for different width of WE electrode. Figures for condition of constant potential and recalculated for constant current are presented

Experiments

Two different phantoms have been developed. The first of them is based on a thin plate of Plexiglas moving under a surface of KCl solution. A cylinder of gelatine mixed with KCl solution is placed on the Plexiglas plate. The second consists two layers of gelatine, however mixed with KCl solution having different concentration thus conductivity. This phantom has a stable form and fixed dimensions.

The first phantom gives the possibility of changing a thickness of upper layer. This is done be means of step motor with a step resolution equal 2,5 μm. It provides the possibility to determine value of impedance as a function of upper layer thickness (Fig. 4). The phantom has been examined with three different concentration of KCl solution: 0.1 mol/l, 0.01 mol/l and 0.001 mol/l. Plexiglas, copper and gelatine have been used as a bottom layer.

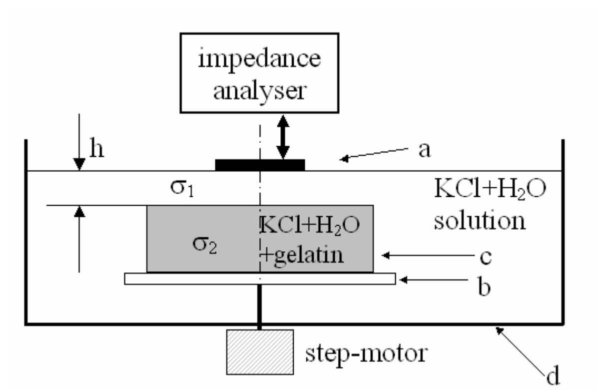

Figure 4: Schematic presentation of first phantom studied; a - annular probe, b- the movable plate of Plexiglas, c - cylinder of gelatine of known conductivity, d - tank filled with solution of KCl

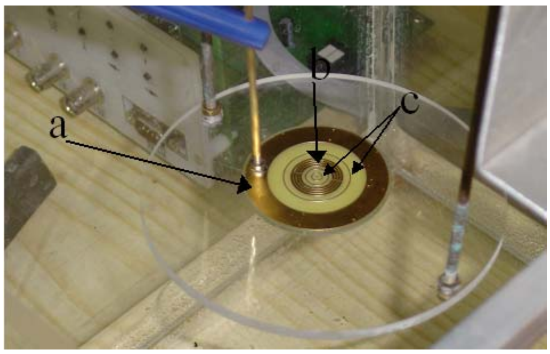

Figure 5: Construction of the probe: a – RE electrode, b – WE elctrode, c - ME electrodes

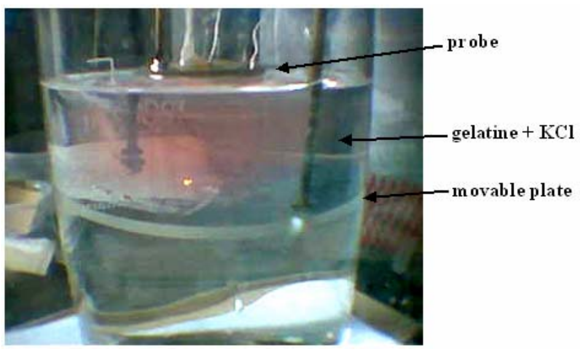

Figure 6: Lateral view of phantom a - annular probe, b - the movable plate of Plexiglas, c - gelatine

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The second phantom has been formed in a cylindrical dish by pouring two layers of gelatine mixed with KCl solution of different concentration. Sixteen phantoms have been manufactured. They differ in layer thickness and conductivity. The concentration of gelatine was selected in order to achieve stable, solid medium (60,5g/l). Only two concentrations of KCl have been used: solution A - 0.1mol/l and solution B - 0.01mol/l. The thickness h2 of bottom layer is fixed and equals 23,5 mm. Different thickness of upper layer, h1, has been achieved by using different volumes of solution. Four different thickness of upper layer have been prepared (Table 1).

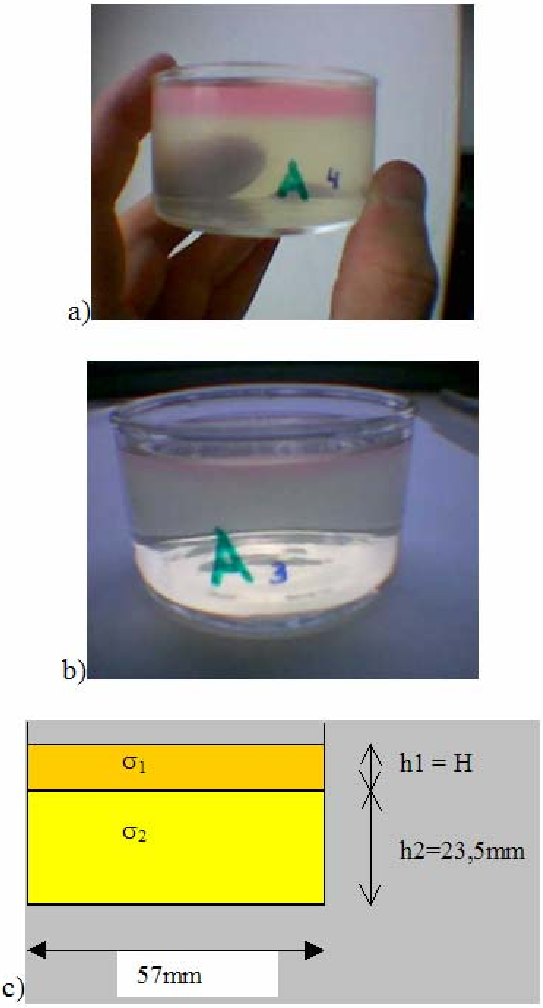


Figure 7: Gelatine phantom, a) and b) the upper layer is pink coloured in order to be visible; the thickness of the upper layer for phantom marked A4 equals 6,2 mm while for one marked A3 – 3,1mm, c) the bottom layer has the same thickness in all phantoms

Table 1: Dimensions of upper layer of gelatine

volume of solution	h1 [mm]
2 ml	0.7842
4 ml	1.5683
8 ml	3.1367
16 ml	6.2734

An electronic interface located between the probe and Solartron SI1260 has been developed. The probe used in experiments has 3 different ME electrodes and WE consists of 4 rings. The applied excitation is voltage one and is applied between WE and RE electrodes. The current flowing through RE electrode is measured using I/U converter (Fig. 8). The potential on the top surface of the phantom is measured by ME.
Thus, apparent impedance, measured on the surface of the layered structure, is defined as:

$$Z_a = \frac{U_{in}}{I_{in}} = \frac{U_{in}}{U_{wy}} \cdot R_I \qquad (1)$$

where U_{in} – voltage, I_{in} – current, R_I – resistor of current to voltage converter

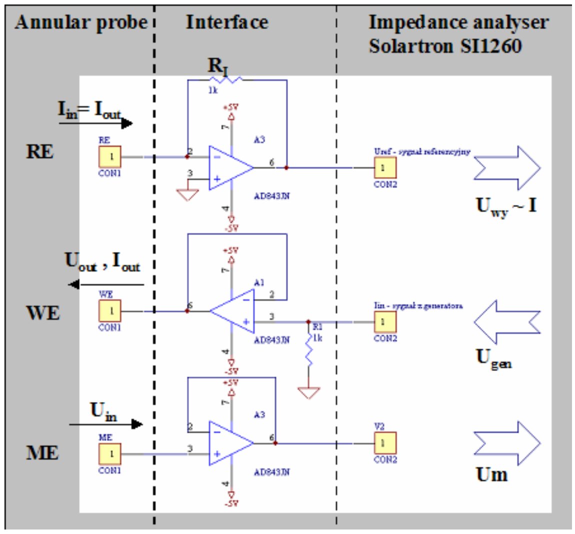


Figure 8: Schematic presentation of interface circuit between the probe and Solartron

To evaluate actual conductivity of gelatine and KCl solution additional measurements have been performed after phantom examinations. They have been examined by means of four-electrode cell (Figure 9).

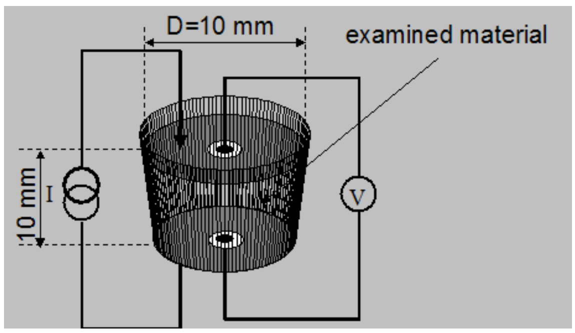


Figure 9: A schematic presentation of the measurement cell used for examination of gelatine and KCl solution conductivity

The measured conductivity of gelatine mixed with KCl solution, used for layer #1 and #2, are 11,6 mS/cm and 3,6 mS/cm, respectively (module of impedance at frequency of 1 kHz excitation current). Thus, the conductivity of gelatine samples differs, as expected, from conductivity of KCl solutions.

Results

In order to determine the conductivities of both layers and the thickness of the external, multiple, independent measurements must be done. We achieve such independent measurements by changing the width of working electrode WE, by switching constituent rings, or/and by changing the place of ME. Series of independent measurements allow construction of characteristic shapes of curves, which can show the depth of external layer and relations between conductivities.

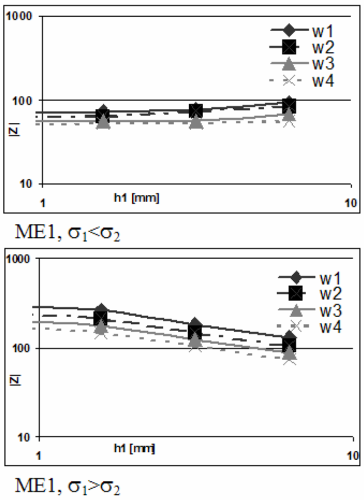
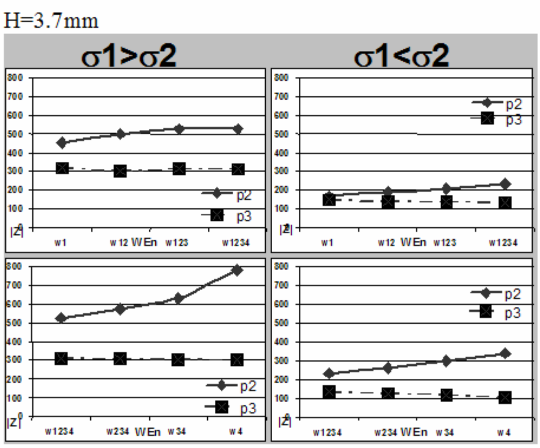


Figure 10: The raw data and approximating curves for different conductivity relations and different thickness of upper layer

A good separation between curves of impedance is obtained for different conductivity and thickness upper layer. The developed stand allows collecting measurement data for the prescribed parameters of the layered structure in automatic manner. Examples of such data are presented in Figure 12.



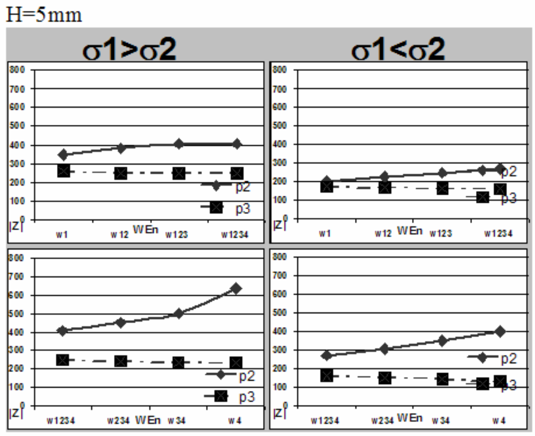


Figure 11: Result of measurements obtained for different set of WE and ME electrodes for a given upper layer thickness and conductivity ratio

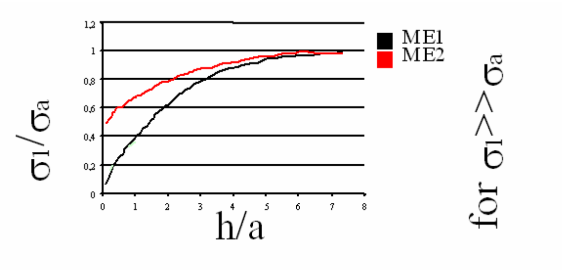


Figure 12: Potential measured at two locations as a function of layer thickness

Conclusions

The developed phantom appears to be very useful for determination of properties of different types of probes and their applicability to determine the conductivity and thickness of the relatively thin layer. The results obtained prove the ability of impedance technique to distinguish between differently structured objects.

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