The current flow modelling in a sensor with the active shield

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Abstract— **The concept of an active shield has been originally introduced for constant current sources. The main issue of an application of the active shield is a delimitation of the current flow to an object or its part situated exactly between current electrodes. Therefore more reliable impedance measurement results could be obtained. The active shield is an electrode that surrounds the current electrode and adopts its electric potential. Modelling of the current flow was carried out using the Finite Element Method in 2D space. The electric potential of the active shield was set in an iterative process. Initially, the electric potential of the active shield was set to zero. After a simulation, the potential of the active shield was changed to the potential of the current electrode and the simulation was repeated until convergence was obtained. Current flow modelling has been performed with and without the active shield in two different set-ups: in homogeneous environment and with large heterogeneity outside a shielded area. The distribution of the current density and electric potential gradient confirm theoretical considerations. Using the sensor with the active shield, current is injected perpendicularly to the current electrode surface due to equal electric potential on a parallel plane.**

Keywords— **active shield, FEM modeling**

I. Introduction

A problem of a delimitation of the current flow in the tissue is often encountered in bioimpedance measurements. It often happens when the measured area possesses greater impedance than the tissue around it. One of the possibilities of limiting the current flow in the measured object is surrounding the current electrode with an electrode/electrodes of the potential equal to the potential of the current electrode. In this way it is possible to force the measuring current flow in the desired direction [1].

The current flow in 2 D surface with the active screen switched on and off has been modelled in the present paper. Conclusions following the performed modelling can be used both in the 2- and the 4- electrode measurement [2].

II. Method

Modelling has been carried out using a Finite Element Method (FEM) [3]. Calculations have been made in a Matlab's toolbox i.e. "Partial Differential Equation" [4]. There are the following stages in the modelling process:

- defining the calculation space,
  a. specifying the geometry of the objects in the calculation space,
  b. defining boundary conditions,
  c. specifying electric properties of the objects,
- using iteration algorithm to specify the potential/voltage value at the active screen,
  a. carrying out the modelling using the finite element method for a specified potential/voltage at the active,
  b. increasing the value of the potential/voltage at the active screen up to the value of the current electrode potential/voltage,
  c. cyclic repetition of the above-mentioned two stages until the same potential at the active screen and current electrode has been obtained.

A. Defining calculation space

The calculations have been carried out in 2D space limited to a rectangle. Two rectangles corresponding to the current electrodes, around which two rectangles modelling the active screen electrodes have been placed, have been defined in the scope of the calculation space (Fig. 1).

The boundary conditions have been defined with the use of the Dirichlet's condition (1) or Neuman's condition (2):

$$h \cdot V = r \tag{1}$$

$$n\sigma \cdot \nabla V + q \cdot V = g \tag{2}$$

where h is weight, r is electric potential, q is film conductance while g is current source.

Hermann Scharfetter, Robert Merva (Eds.): ICEBI 2007, IFMBE Proceedings 17, pp. 8–11, 2007

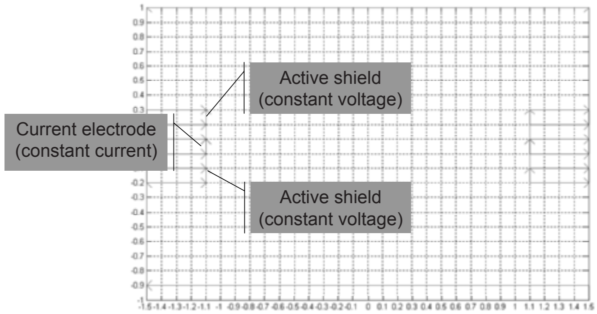

Fig.1 Calculation space and its components

The calculation space has been enclosed by a conducting material (h =1, r = 0 in the Dirichlet's condition) of a zero potential. The active screen contact surfaces have been also modelled with conducting material of a zero potential at first (h =1, r =0 in the Dirichlet's condition). Constant current is injected through the contact surface of the current electrode (g =±1, q=0 in the Neuman's condition). The electric values of the modelled objects have been defined by assigning appropriate values to the parameters of the elliptic equation:

$$-\nabla \cdot (\sigma \cdot \nabla V) = q \quad (3)$$

where σ defines conductance and q is a current source. A dielectric have been introduced between a current electrode and an active screen electrode (σ =1e-5) whereas for the remaining area σ =1.

B. Specifying the value of potential at the active screen

The value of the potential at the active screen has been calculated using the iteration algorithm. A zero potential/voltage at the active screen has been assumed in the first iteration. The calculations for the parameters of the above – mentioned model have been made using the finite element method.

Triangulation of the calculation space has been performed and then an elliptic equation (3) has been solved in each division node interpolating the calculation results between the nodes. Next, the current electrode potential/voltage has been assigned to the active screen and the modelling using finite element method (FEM) has been carried out once more. The process has been repeated a few times obtaining the same potential/voltage at the active screen electrode and the current electrode (Fig. 2). The change of the potential/voltage at the active screen electrode depending on the iteration number has been presented in Figure 3. The potential/voltage at the active screen and the current electrode is already similar at 3rd and 4th iteration.

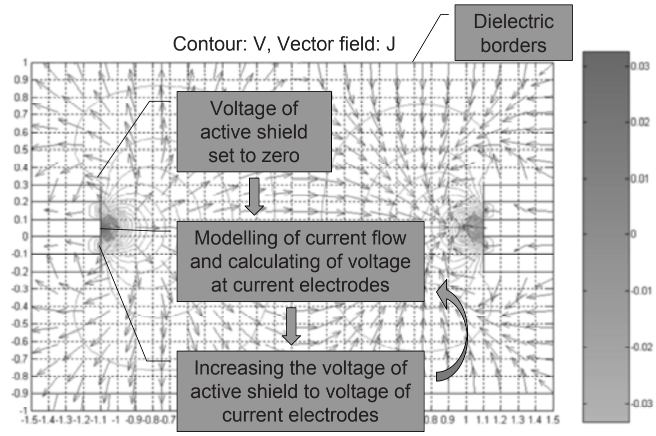

Fig.2 A diagram of the iteration algorithm specifying the potential value at the active screen

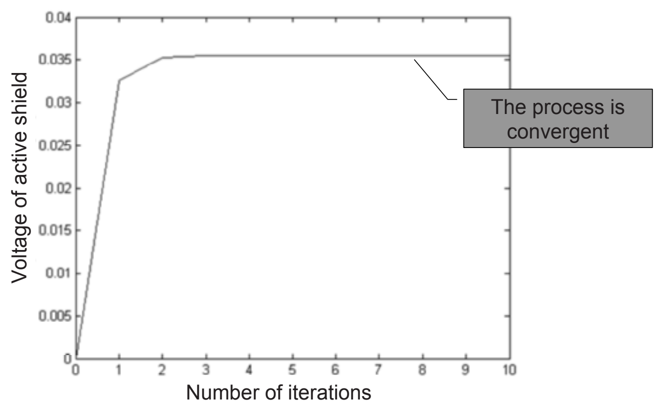

Fig.3 Change of potential at the active screen in subsequent iterations

III. Results

The distribution of the current density and electromagnetic field in the case when the active screen is switched on and off has been presented in the Figures below. The current density distribution in the vertical line passing through the middle of modelled area has been presented in Figure 5. In the case when the active screen is switched off the whole current originates from the current electrode and spills all over the modelled area (a blue line). When the active screen is switched on the current flowing from the current electrode is mostly limited to the central part of the modelled area whereas the sides are "powered" by potential/voltage electrodes. Since only the current from the current electrode is taken into account in the impedance measurement, only the area between the active screens is included in the impedance measurement.

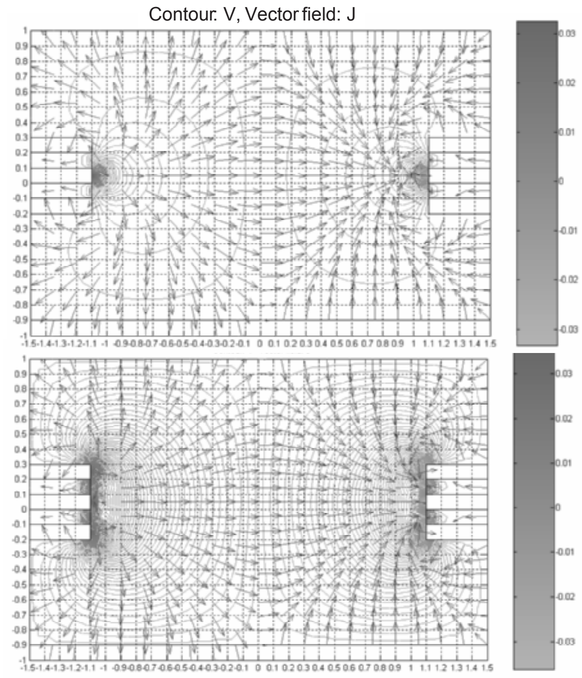

Fig.4 Current flow modelling and electromagnetic potential values in the case of switched off (up) and switched on (down) active screen.

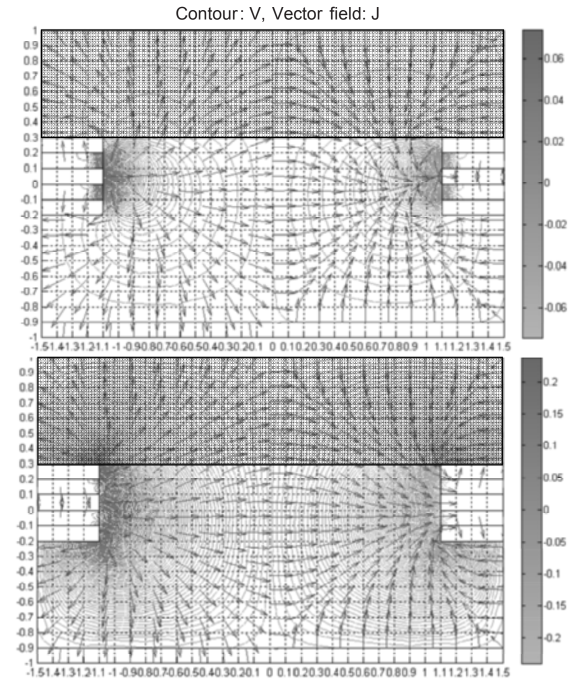

Fig.6 Modelling of the current flow in the sample of great heterogeneity with the active screen switched on and off.

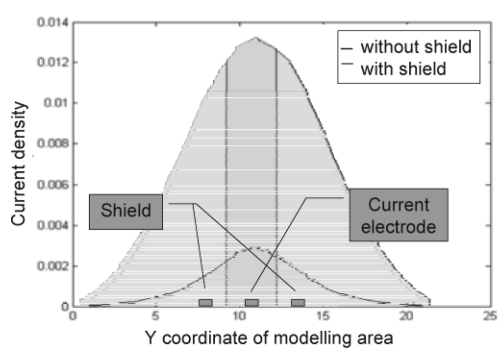

Fig.5 Distribution of current density along the vertical line passing through the middle of the modelled area. The description is included in the text.

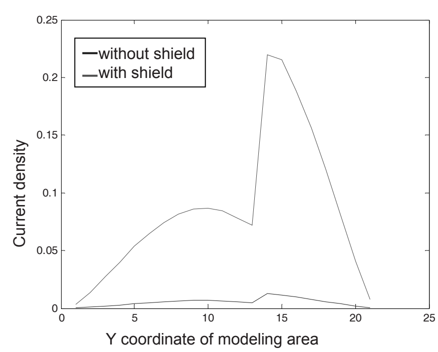

Fig.7 Distribution of the current density along the vertical line passing through the middle of the modelled area. The description is included in the text.

An analogous simulation has been carried out after introducing into one homogeneous sample great heterogeneity of lower impedance at the level of the upper active screen electrodes. In such a situation with the screen switched off large part of the measured current has been flowing through the heterogeneity which is the area of smaller impedance. After switching the active screen on the potential of the screen electrode made the flow of the current into the heterogeneity impossible.

IV. Discussion

The phenomena occurring at the interface of electrode-sample have not been modelled, e.g. electrochemical effects. However, assuming that the processes at the interface/contact surface at the current electrode and the active screen electrode are identical the distribution of the current density along the line passing in the middle should stay alike in both cases.

The modelling has been performed only for the constant current. Performing a similar modelling for the alternate current is possible but the calculations should be made in complex plane space such as Matlab Toolbox "Partial Differentia Equation".

V. Conclusions

Application of an active screen diminishes the area the measuring current flows through. It requires however using greater total current because of the necessity to increase the potential at the active screen. This effect can be used in bioimpedance measurements. It is expected that higher reproducibility results will be obtained with the electrodes with active shield. The usage of active shield may result in higher clinical resolution of bioimpedance measurements.

References

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