XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6−11, 2009, Lisbon, Portugal

REQUIREMENTS OF A MECHANICAL POSITIONING SYSTEM FOR BIOLOGICAL IMAGING USING MAGNETIC INDUCTION TOMOGRAPHY

Nuno B. Brás[1], *P. A. F. Martins*[2], *Raul C. Martins*[3], *António C. Serra*[4]

[1,3,4]Instituto de Telecomunicações, IT
Instituto Superior Técnico, Torre Norte, Piso 10
Tel: 00 351 218418489, Fax: 00 351 218417672
[2]IDMEC, Instituto Superior Técnico, TULisbon, Portugal
[1]nuno.bras@lx.it.pt, [2]pmartins@ist.utl.pt, [3]rcmartins@lx.it.pt, [4]acserra@ist.utl.pt

Abstract – Magnetic Induction Tomography (MIT) is an imaging technique that allows mapping the complex conductivity structure of a body by measuring the magnetic field generated by currents induced within the body. Typically, MIT systems are static since their sensing positions and the angular incidences of the main magnetic field do not change. Recently the authors from IT developed an experimental setup with movable coils and body to increase the number of measurements. In this paper, a new moving system of sensing coils and body plate is analysed and its importance is highlighted. The accuracy and the measurement requirements for the positioning setup are studied, namely the influence of the displacement error on the measured electromotive signal at the sensing coils for each position. Results from the implemented experimental system are reported and its overall importance is highlighted.

Keywords: Magnetic Induction Tomography, Eddy Currents, Angular Measurements

1. INTRODUCTION

Magnetic Induction Tomography (MIT) [1] is an imaging technique for passive electrical properties based on measuring induced magnetic fields imposed by an external source inside the body in analysis, allowing reconstruction of its internal structure. In the case of biological tissue bodies, the major electrical property to be characterized is the complex conductivity. Bodies to be analyzed have some tens of centimetres, characterized by small changes on conductivity between distinct tissue types (0.5 S/m). Typically, frequencies ranging from some tens of kHz to some MHz are used in the excitation magnetic field. This context requires the existence of a high resolution method for measuring the magnetic field induced in the body and the ability to acquire data at several points along its border, for several excitation sources, in order to reconstruct the body conductivity map (see, e.g. [2]).

In previous work [3] the authors focused on the idea of increasing the number of measurements used for reconstructing the body. A preliminary prototype that allowed the rotation of the sensing coils while at the same time the rotation and vertical displacement of the body plate was proposed which enabled us to study image reconstruction using an optimum set of measurements for each body in analysis. However, as shown later in presentation, the lack of positioning accuracy (nearly 40 mº) hindered the electromotive measurement resolution. Also in previous work, we developed a new cancelation technique called Twin Coils Setup that was kept in the implementation of this prototype. The novelty consists in placing the source at the centre of a circular setup, and the sensing coils positioned at opposite sides of the circular layout. The half circle where the object is placed is then measured differentially. It is important to notice that the size of the circular layout is should be enlarged in order to house the same body sizes. In Fig. 1, the classical architecture and the new one are presented side by side.

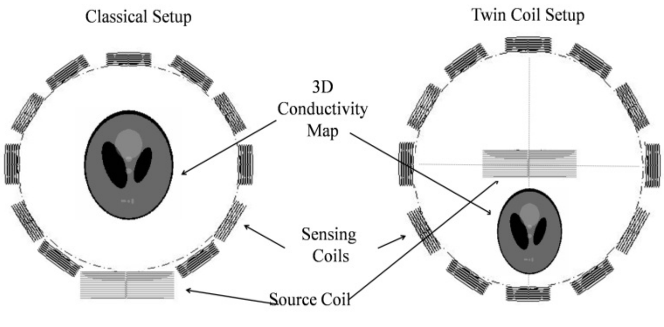

Fig.1 Comparison Between a classical Geometry and the Presented Prototype Geometry, upper view.

The new setup has several advantages over the classical circular setup: (i) it allows for differential measurements for better excitation field suppression, as is the case of planar gradiometers [4], but it does not generate ambiguous conductivity spots with symmetric values which is one of the gradiometers drawbacks [4] (ii) the carrier amplitude does not vary considerably along positions, meaning that due to its symmetry no position is preferential.

The main drawbacks are: (i) it is intrinsically noisier since the differential signals are not in the same PCB as the planar gradiometer. (ii) Intrinsically to any system, there is a calibration process that has to be done *a priori*, which might give rise to additional errors in the case of a moving system.

To understand the measurement requisites that compel the development of a high resolution positioning system, the implemented experimental acquisition scenario for this setup is described. The distance between sensing coils and the source is equal to the sensing circle radius, which is 20 cm. The source coil has a diameter of 5 cm while the sensing coils have a diameter of 3 cm. A 0.5 A current at 870 MHz fed to a coil source, given the setup geometry will induce an electromotive force of ~100 mV at each coil. This value was experimentally obtained.

In what concerns the necessary measuring conditions: the signal to be measured satisfies a Signal to Carrier Ratio (SCR) of 10^{-7} [4]. This is the value that allows to measure biological tissues. In this condition, the necessary signal standard deviation is in the order of magnitude of tens of nV (since the carrier has 100mV amplitude).

In the case of the twin sensing coils setup it was experimentally found that a residual voltage is always present since no perfect geometric alignment between sensors and source coil exists. External interferences will always influence the differential measurement and no perfect balancing of each side of the twin sensing coil pair can be made. Residual signal amplitudes could be found between 10 µV and 400 µV when rotating the sensors (see section 3).

Since the residual amplitude is actually bigger than the signal to be measured and since it is not constant along the angular path, an a priori calibration has to be made. The procedure consists of identifying the residual value for each position to introduce it as compensation during the measurement stage. Since the residual voltage could be strongly dependent on the sensing coils position and, hence, change the position between calibration and measurement stages, the sensing coils positioning system is critical. Measurement itself is at stake. The other positioning components (rotation and vertical movement of the body plate) are not as important because they only reflect the acquisition positioning in the reconstruction process. However, they do not affect the measurement.

This paper is focused on the positioning accuracy of a new prototype where special concerns with the moving system were taken, along with a quantitative numerical study of how accurate it should be in order to reduce the angular positioning error propagated to the final measurements. First experimental results are shown, using the lowest resolution system. Error results from an imperfect calibration are presented for a moving acquisition scenario.

2. PROTOTYPE DESCRIPTION

2.1. Mechanical Description

The mechanical assembly of the new prototype provides three degrees of freedom. The sample holder can (i) rotate around its axis and (ii) move up and down while the support structure for the sensing coils (henceforth rotary table) can (iii) rotate around its axis (refer to the schematic plot of the degrees of freedom in Fig. 2). As said, the main component of the system is the rotary table. It is positioned over a fixed base and supports the sensing coil holders, placed at the rim (500 mm diameter), to turn around the vertical axis by approximately 240 degrees (although just 180 degrees are used).

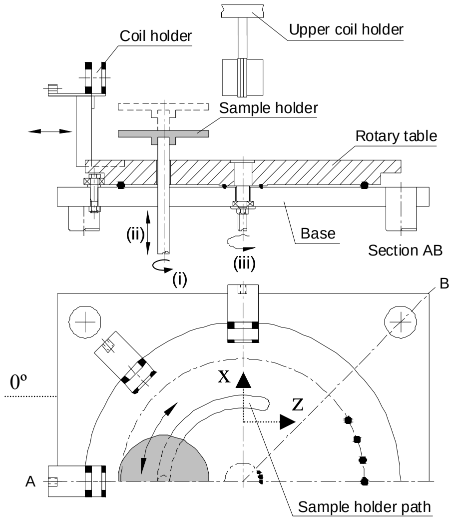

Fig. 2 Schematic drawing of the mechanical system

The coil holders are radially adjustable (V-slots were anticipated during the design for this purpose) and the contact between the rotary table and the base is made by two sets of glass balls rolling in between the upper and lower races. The glass balls ensure parallelism between the rotary table and the base while sleeve polymer bearings located at the outside diameter of the table prevent any other direction of motion. A frame is assembled over the rotary table in order to mount the support arm of an upper source coil holder.

The components of the mechanical system were manufactured from rods and plates of Polyoxymethylene (POM). There are no metallic components in order to avoid interference with the magnetic field. The overall design is corrosion and lubrication free making it ideal for a clean room environment. In Fig. 3, a photo of the setup is shown, with the V-slots and a detail of the millimetric screw which enables an improvement of the radial sensing coils positioning accuracy.

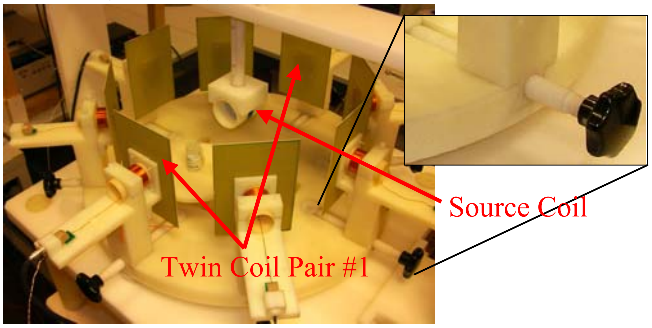

Fig.3 Photo of the prototype and detail of the millimetric screw used for positioning the sensing coils and improving the excitation field cancellation

2.2. Motor Driver and Angular/Displacement Sensing System

The three degrees of freedom are controlled by a microcontroller that generates PWM signals to a H-Bridge.

The power signal is demultiplexed by the microcontroller using two relays to feed the correct DC motor. Absolute optical angular encoders are used to measure the angular sensing coils and the body plate position. The accuracy and resolution of these sensors are studied in the next chapter. A displacement encoder is used to measure the only linear displacement degree of freedom which is the body plate vertical position. All sensing signals are digital serial inputs of a 16-bit microcontroller and they are used in the feedback control of each motor. In Fig. 4 the referred system is depicted:

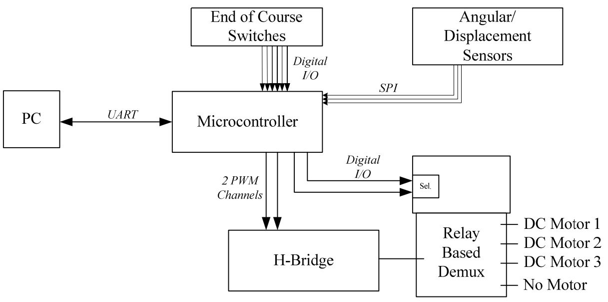

Fig.4 Schematic of the developed driver to control the three degrees of freedom.

2.3. Electronic and Electromagnetic Description

In an experimental scenario, 4 sensing coil pairs are placed over the rotary table. Moving the table 45º it is possible to cover any desired angular position within 180º (although coils cover the 360º angular space).

Each pair of opposite sensing coils is directly connected to a pre-amplification circuit input. As said, coils could be radially moved, positioned in such a way as to obtain the least residual signal for each twin sensing coil pair. The used source current can generate a 0.5 A amplitude sinewave at 870 kHz. Sensing coils are connected to differential shielded cables that are grounded at the pre-amplifier stage. Inside each shielded cable, the differential cables are twisted in order to reduce magnetic induction.

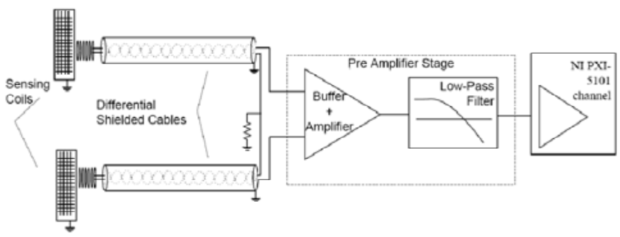

Fig. 5 Acquisition channel detail

Two differential wires, each coming from a distinct sensing coil of the twin pair, are connected in order to subtract the electromotive forces, in an antiseries configuration. Inside each shielded cable, the differential cables are twisted in order to reduce magnetic induction. Two differential wires, each coming from a distinct sensing coil of the twin pair, are short circuited in order to subtract the electromotive forces.

Careful has been taken in creating symmetric paths for each twin coil signal, before adding the signals. Electrical capacitance shields based on orthogonal combs were applied to each coil (see Fig. 3). Since electrical disturbances in the source are not a common mode perturbation in the twin pair, if this effect is not well cancelled it will be present in the residual signal as disturbances. The signal is fed into a differential amplifier with variable gain between 2 and 130. The ADC system used is a PXI 5105, with 12 bits, up to 60MS/s and 8 simultaneous sampling channels, using the lowest distortion input range, 200 mV peak to peak. At this moment just one twin coil pair is being acquired.

3. RESULTS

Two types of results are presented. Firstly, a numerical analysis is shown where the effect in the final measurement after calibration of the 5 mº angular positioning error is predicted. Secondly, a preliminary experimental calibration is presented showing how the positioning error affects the measurements.

3.1. Angular Positioning Error Propagation: Numerical Analysis and Experimental Results

This section of the paper follows a previous study for the classical setup that was presented in reference [5] with the aim of extending the methodology to the new prototype. Here, a detailed study for the new geometry will be presented. The code was implemented in Matlab. The Biot-Savart equation was used to determine an approximated analytic solution to the electromotive forces generated in each coil when no body sample is placed in the body plate. The corresponding differential measurements obtained for each twin coil pair (residual value) is then easily approximated by subtracting the electromotive forces in each coil of a twin coil pair. As previously mentioned, for a completely aligned geometry, with no external interferences and a perfect balance between each side of the twin sensing coil pair, the residual value would be zero. However, if any of these requirements fail a non-zero residual value in any differential twin coil pair is measured. The simulation took into account the geometrical misalignment given by a small deviation of the source coil in respect to the centred position in the z axis (see Fig. 2). We analyzed several source coil misalignment values, from 15 µm to 10 cm, corresponding to residual values from 10 µV to 50 mV (10 µV was the lowest residual value verified experimentally, although not completely resulting from geometric misalignments; 10 cm is a good maximum value in the linearity study of the residual electromotive value with the source displacement). In Fig. 5 a bi-logarithmic plot of the residual value versus the source coil misalignments is shown, enlightening how misalignments theoretically affect the measurements for three rotary table angles, 30º, 90º and 130º. Note that for these simulations a current value of 500 mA was used. A higher current value will increase linearly the electromotive error of the residual values.

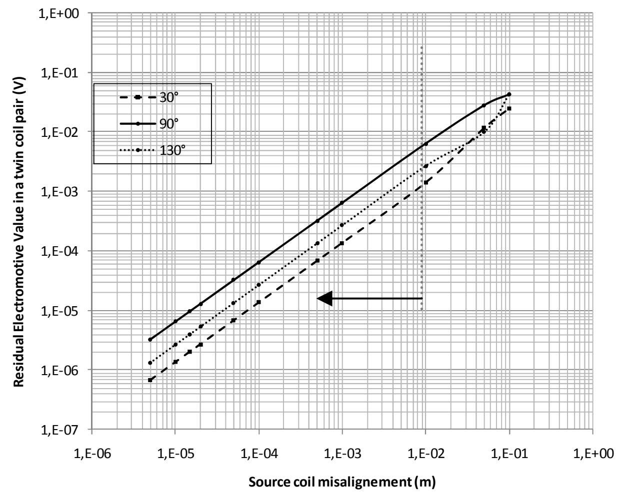

Fig. 6 Residual signal evolution with the Source Coil Misalignment for three position angles of the rotary table (30º, 90º and 130º).

The reference angle of the rotary table, 0º, is shown in Fig. 2. It is found that the relation between the displacement and the residual value is linear until the centimetre scale. This means that the influence of the error is linear for the scale of source coil misalignments that in practice are found.

The sensitivity of the resultant residual value to several angular misplacements between the calibration and the acquisition stage can be calculated by comparing the residuals from the correct position with residuals from the misplaced angular position. 350 µV is a reasonable maximum residual value experimentally measured, which corresponds, according to the numerical simulation, to a source coil error in the z coordinate of 500 µm. This value was used as the source coil positioning error in the next result. In Fig. 6, left side, a numerical simulation of three angular rotary table misplacement errors is presented: 40 mº, 5 mº and 100 µº. An acquired angular profile along a 20 º to 160 º angular sweep of the rotary table is shown. Surprisingly, the relation between the angular errors and the resulting residual signal error is found to be linear. This relation is shown in the right side of Fig. 6.

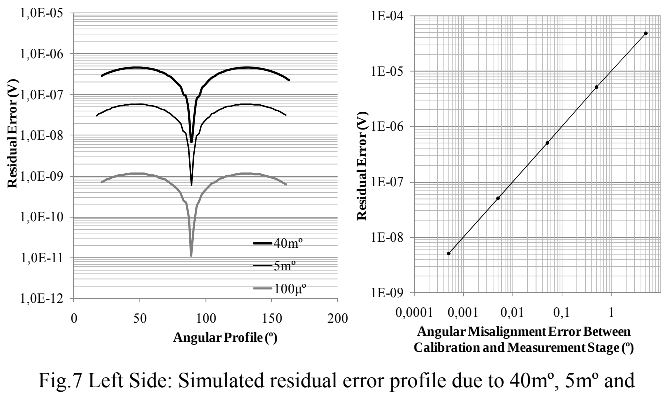

Fig.7 Left Side: Simulated residual error profile due to 40mº, 5mº and 100 µº misalignment errors between calibration and measurement stage; Right Side: Linear relation between the residual value and the angular misalignment errors between calibration and measurement stage.

In the left side of the figure three resolution sensors are studied: an equivalent 10 bit sensor (resolution used in the previous setup [5]) corresponding approximately to 0.24 º nominal resolution and ~ 40 mº measured angular accuracy. A 16 bit sensor, corresponding to ~ 5 mº resolution and a 100 µº equivalent resolution from a magnetic displacement sensor. In the last two cases only resolution was used since sensor accuracy has yet to be tested.

The validity of the calibration process and hence, the positioning system, is done by comparing the instability of the acquisition system for a fixed position and the angular profile after applying the calibration to a moving acquisition. In the next figure, this profile is shown for the 40 mº angular accuracy used in the first implemented prototype. Instead of having a continuous function, spikes are found due to inaccuracies in the positioning system.

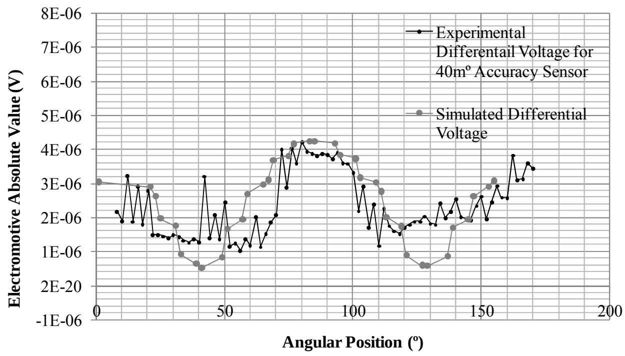

Fig. 8 Residual profile after calibration along 160º for a 40mº accuracy positioning sensor and expected Differential Voltages. The relevant issue is the spikes in the Experimental (black) line due to inaccuracies in the positioning system.

We are setting up the sensing system for the other referred sensors, identifying mechanical hysteresis and other possible effects from the positioning feedback system.

4. CONCLUSIONS

The impact of each mechanical degree of freedom on the final measurement of the sensing coils was presented. The sensing coil rotary table was studied in detail since its error has direct impact on the measurements.

On this subject, the angular position propagated error was studied in order to understand how small geometrical deviations can influence calibration and acquisition process. These studies lead to the conclusion that using a 100 µº resolution positioning system no influence on the measurement can be found on the acquired profile for a 500 mA current in the source coil, since the error is less than the order of magnitude to be measured, assuring in this way a consistent calibration process.

Other sources of error should be taken in consideration as external interferences and misbalancing of each side of the twin sensing coil pair, but their impact is more difficult to predict.

In this moment other geometries are being considered in order to reduce the effect of error displacements of sensing coils positioning, such as using a different alignment of the source coil. The impact of such geometry is being studied in terms of the reduction of the measured signal amplitude in the sensing coils for the same current values in the source coil.

It is important to enforce the relevance of this study. Since this system is able to move the sensing coils without interference on the measurements a more stable reconstruction of the conductivity map could be attained by taking measurements on a higher number of anchor points.

ACKNOWLEDGMENTS

Nuno Brás was sponsored by the Portuguese Ph.D. 309 scholarship program from FCT (SFRH/BD/17405/2004). This work was sponsored by the FCT research project POSC/EEA-ESE/60397/2004.

REFERENCES

[1] H. Griffiths, W.R. Stewart and W. Gough, "Magnetic Induction Tomography, a measuring system for biological tissues", Ann. NY Acad. Sci. no. 873, pp. 335-345, 1999.

[2] Manuchehr Soleimani and William R. B Lionheart, "Absolute Conductivity Reconstruction in Magnetic Induction Tomography Using a Nonlinear Method", IEEE Transactions On Medical Imaging, vol. 25, No 12, December 2006.

[3] Nuno B. Brás, Raúl C. Martins, António C. Serra, "Characterization of a New Symmetrical Cancelation Method for Magnetic Induction Tomography", 16th IMEKO TC4 International Symposium Proceedings, pp 922-927, 2008.

[4] J. Rossell, R. Casañas and H. Scharfetter, "Sensitivy Maps and system requirements for magnetic induction tomography using a planar gradiometer", Physiol. Meas., no. 22, pp. 121-130, 2001.

[5] Nuno B. Brás, Alexandre Pestana, Raúl C. Martins, António C. Serra, "Dimensioning and Characterization of a New Magnetic Induction Tomography Experimental Setup", I²MTC 2008 Proceedings, pp 2131-2136.