Characterization of a New Symmetrical Cancelation Method for Magnetic Induction Tomography

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Abstract- *Magnetic Induction Tomography (MIT) is an imaging technique for passive electrical properties used in industrial and biological imaging. In the case of biological purposes, high resolution measures of the magnetic field induced in the body and the ability to acquire data at several points along its border are two major challenges of MIT. In a previous work we have developed a prototype that allows accurate placement of sensing and source coils, improving data quality and quantity for the tomographical image processing. Several alternatives for stability and resolution improvements have been presented. However, all of them had limitations in terms of stability and resolution for a moving coils system. This paper presents a new geometric setup designed for a moving sensing coils prototype that allows the cancelation of the carrier field independently of the acquiring position.*

I. Introduction

Magnetic Induction Tomography (MIT) [1] is an imaging technique of passive electrical properties by 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. Although relative permeability could be also interesting [2] in terms of diagnostic, normally it is considered to be constant and equal to 1. Bodies to be analyzed have some tens of centimeters, characterized by small changes on conductivity between distinct tissue types. Values to be measured should be on the order of magnitude of 5 S/m, and low conductive tissues could be as low as 0.1 S/m. Typically, frequencies ranging from some tens of kHz to some MHz are used as the excitation magnetic field.

The standard MIT setup is mechanically static with several sensor coils and source coils mounted in a cylindrical wall around the object [1]. The object should rotate in order to be irradiated from several angular positions. The space in test is normally a cylinder with around 15 to 30 cm diameter with sensing coils aligned in the same horizontal plane.

The vector field $\boldsymbol{\Delta V/V}$ called signal-to-carrier ratio (SCR), relates the voltage induced in a sensing coil by the body induced magnetic field ($\boldsymbol{\Delta V}$) with the voltage induced in that sensing coil by the magnetic source field ($\boldsymbol{V}$). The minimum measurable quantity of SCR is intended to be a system performance indicator. However it lacks an important property, that is, what kind of conductive material corresponds to $\boldsymbol{\Delta V}$. In biological tissue measurements, SCR absolute values can be as low as 10^{-7} [3]. However, 10^{-5} values could be enough to reconstruct higher contrast images. Since the change of conductivity and permittivity results in a small change of the magnetic field ($\boldsymbol{\Delta B}$) over the carrier field ($\boldsymbol{B}$), it is required both high resolution and high range to measure $\boldsymbol{\Delta V} + \boldsymbol{V}$. The cancelation of $\boldsymbol{V}$, obtaining a residual ($\boldsymbol{V'}$), with a low noise corruption of $\boldsymbol{\Delta V}$ allowing a theoretical full scale ADC conversion of $\boldsymbol{\Delta V}$ ensuring signal stability is a key issue in any MIT experimental setup.

In a previous work we presented a MIT prototype that allows virtually any sensor position acquisition, by moving the sensors around the object [4]. It allows also moving the object relatively to the source, creating any desired incident angle.

Two kinds of problems arise for a MIT moving system: Mechanical positioning should be precise enough so that measures are not affected by positioning errors, since a calibration should be done without the object exactly in each acquiring position. In [1], a classical MIT cylindrical setup was studied and 5mº error was found to be necessary so that propagated mechanical errors are 20dB lower in most space analysis than measured biological tissue signals. Also, in a classical setup the cancelation factor ($\boldsymbol{V/V'}$) for all positions can change along the acquisition path. This effect makes more difficult the signal conditioning for a stable amplification of the residual $\boldsymbol{V'}$ since it is not fixed when rotating the body.

In this paper, a new setup designated here as the twin setup is presented. In this setup, the source is placed at the center of a circular platform, and two sensing coils are positioned in a circumference at opposite sides. This setup stabilizes the cancelation factor along positions and allows differential measurements in the same logic as gradiometers, but improving the amplitude of the residual (***ΔV***) for the same conductivity body, making a higher SCR from images of lower contrasts than using the standard system. Also, due to its symmetry, common mode noise is theoretically cancelled and electrostatic shielding is more effective.

II. Proposed Setup

A. Mechanical Features and Measurement Considerations

The used prototype was presented and characterized in [4]. Geometrically, the prototype is composed of three plates mounted over each other. The source plate, where the source coil is mounted, is a static plate. The sensors plate and the body plate have independent rotating drives, allowing that both the sensors and the object rotate around the vertical axis. This particular Twin Setup has a symmetric positioning of the sensing coils in respect to the source coil.

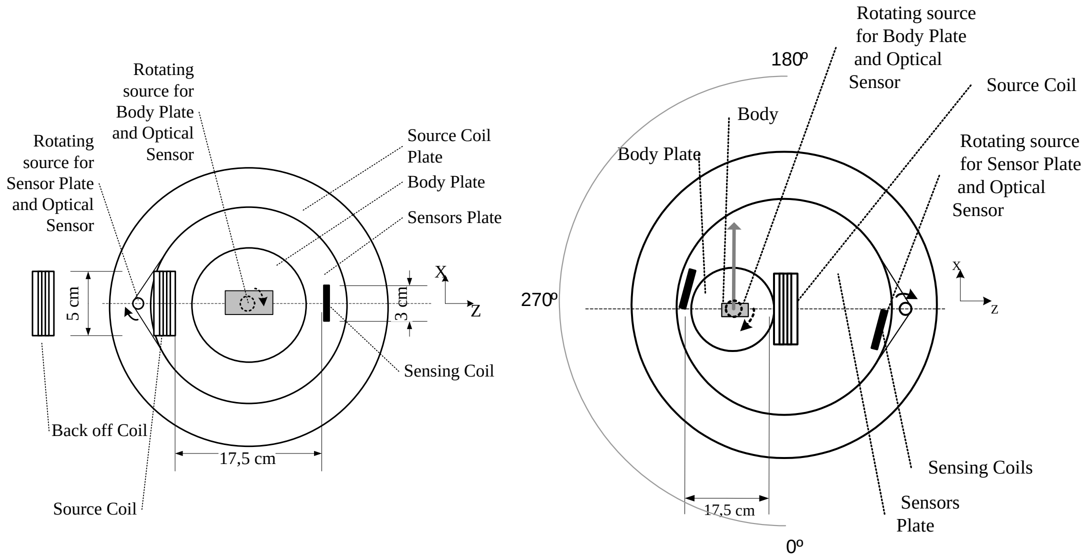

Fig.1 – Geometry Schematics, on the left the standard setup, on the right the Twin Setup, both viewed from top.

The setup logic is based on an axial symmetry in relation to the vertical axis that passes through the center of the sensing coil plate, that is, the place where the source coil is centered. This symmetry allows a theoretical cancellation of the incident field (***V***) for all sensors positions.

The source coil should be exactly in the center of the plate and sensing coils should be aligned in a radial fashion at symmetric position in relation to the center.

In the traditional setup, a back off coil is typically used to measure the real incident field and is used as the system reference. Hence, it should not be influenced by the body presence. We have used as reference the current signal measured in the current to voltage resistance using a very high value impedance buffer not to disturb the power amplifier circuit. This avoids direct electromagnetic disturbances on the setup and since the picked up signal is in the order of some volts, it makes a stable reference.

The prototype is made of perspex over a wood structure. All conductive materials are placed in the lower part of the structure, and only perspex and wood objects exist over it. The source coil is made of copper with 5 cm diameter and 20 turns and the sensing coils are coils with 40 turns, electrostatically shielded by a pcb with parallel conductive lines aligned horizontally and vertically respectively in each side of the pcb. Electrostatic shielding is more effective in this type of setup since the source is always in the radial direction and shields are placed tangentially to the sensors circumference. All coils could be displaced in the radial direction over the plates, to define the intended space analysis, which is typically around 18 cm diameter. A photo of the prototype mounted in the referred setup is shown in the figure 3.

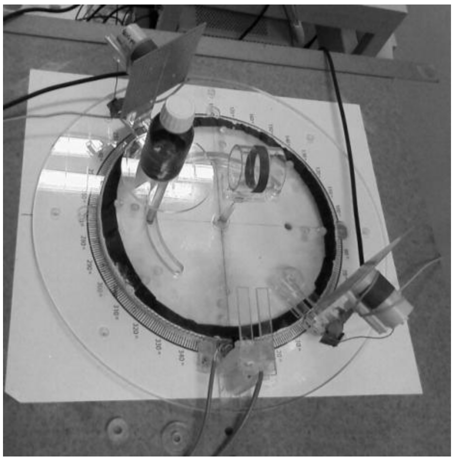

Fig.3 – Prototype Photo

Each rotating system is powered by two motors PWM controlled by the same microcontroller that feeds an H bridge motor driver using a relay to choose which motor to run. The microcontroller controls the position of the sensors according with the needs through a main personal computer. Near the desired position, it forces a smooth negative feedback based on collected data from angular sensors that are mechanically coupled to the rotation source of the Sensor Plate and to the rotation source of the Body Plate.

The most important rotating system is the sensors plate. For this case, although the presented angular sensor has a resolution of 128 positions, since the ratio between the plate and the source drive is 11.9, a ~0.24º resolution is achieved. In terms of precision, the achieved value was of 39 mº.

The measured *emf* when the body is placed in the plate is the difference of both sensing coil voltages. Since this difference is not perfectly zero in the absence of object due to mechanical disagreements and impedances mismatches between the sensors, a residual voltage (***V'***) is seen. When the measured ***ΔV*** is acquired, this residual voltage for each position should be subtracted in order to get the real ***ΔV***. A schema of the voltages in this context is presented in the figure 2.

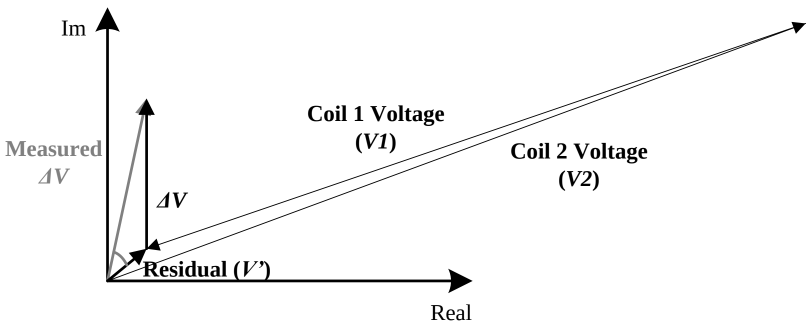

Fig.2 – Complex plane voltage vectors.

B. The Source Field System

A power amplifier mounted as a current source is used, feeding the source coil with currents from 1.25 A for 1 MHz frequency signal to ~2 A at 100 kHz. A high voltage capacitor in series makes an LC resonate circuit reducing the load reactive component.

The source is fed by a generator, which is manipulated by the main personal computer.

B. Acquisition System

The instrumentation schema is shown in the figure 4.

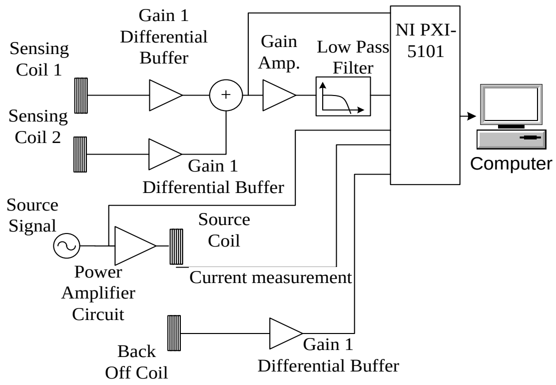

Fig. 4 - Acquisition Schematic and Acquisition Block Diagram

The unit gain differential buffer connected to the sensing coil has 73 kΩ impedance for the maximum considered working frequency, 1 MHz, allowing sufficient cancelling of the current on the sensing coils. After subtracting the sensing coil signals, the resulting signal is either directly acquired or it is amplified with a variable gain, allowing close matching to a full scale of the PXI acquisition system. The applied lowpass filter is a fourth order Chebyshev filter, ideal for fixed frequency signals. It is tuned to fc= 1.2MHz since it is optimized for a 870kHz intended to filter harmonics and spurious high frequencies allowing using a better dynamic range of the PXI-DAQ acquisition board. Acquired signals are the direct residual signal after cancelation, amplified residual signal, the source generator signal and the source coil current value.

The acquisition program was developed in the LabView environment. All signals where acquired simultaneously using a 60 MS/s sampling rate. The accurate amplitude and phase of the acquired signals from the excitation and sensing circuit are obtained using two methods: 4 parameter sine fitting algorithm using the IpDFT method to determine the frequency first estimation [5] or a digital Lock-in amplifier. For each channel, 20k points are processed using these algorithms, typically averaging over 40 acquisition samples.

C. Noise Sources

In the analysis of noise sources, we start by characterizing the source signal generator Agilent 33220A together with the PXI DAQ 5105, with 12 bit resolution, on its smallest scale of 50 mVpp. The LSB value in this case is 12 μV. Using 50 samples of signal amplitudes calculated using the sinefitting measurement technique we got an amplitude standard deviation of 300 nV. In practice, the signal in analysis was small compared with the minimum DAQ range and it should be previously amplified in order to use its full range. Typical measured ΔV signal amplitude values are below 3 mV which suggested a gain equal to 8. The standard deviation is reduced to 150 nV.

To test the noise imposed by the entire signal conditioning electronics, we substituted the sensing coils by the generator feeding with the same signal both the differential amplifiers. The resulting standard deviation was 250 nV.

To measure electromagnetic and acquisition circuit noise standard deviation, it was turned off the source coil. The obtained value was ~150nV. Since some outliers due to incident electromagnetic noise exist, a final median filter was applied.

The used excitation signal has 870 kHz with 1 A. For this current, the measured carrier signal in each sensing coil is approximately 200 mV and a good mechanical positioning of the sensing coils give a resultant maximum residual signal of 3mV. Typical standard deviation of the residual is 4 μV.

III. Acquisition Results

All data was acquired using the referred operational parameters. In figure 5, cylindrical saline solutions of 8 S/m with 30 and 40 mm diameters are shown, with equal height respectively. Besides these known phantom cylinders with known and controlled conductivity we wanted to examine the behavior of the system with much higher conductivity bodies for which we used a small solder ball with 1 cm diameter. Its conductivity is not known and we have assumed in our model the conductivity of tin. Here are shown the profiles of the SCR real and imaginary component when moving the body along a line perpendicular to the axis of the source coil, as denoted by a grey arrow in figure 1. In this case the sensing coils were positioned at 270º, that is, perfectly aligned with the source coil.

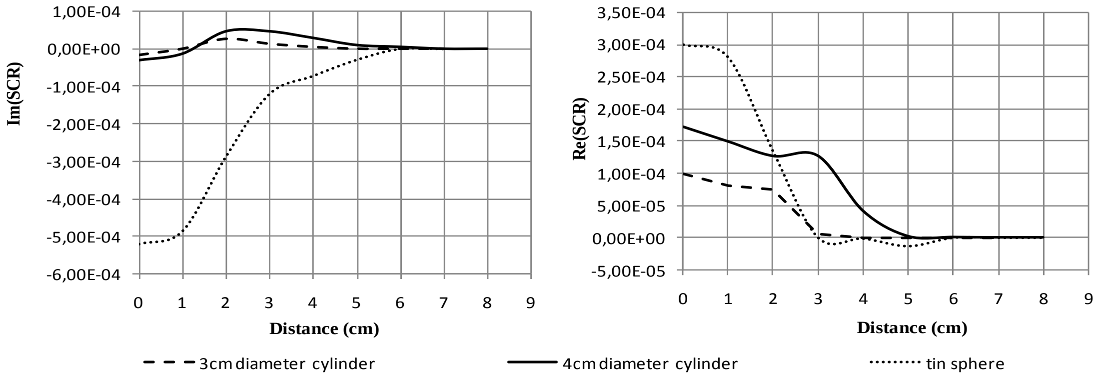

Fig.5 – SCR imaginary component when moving the body along a line perpendicular to the axis of the source coil.

Similar results were presented in [1] where the same behavior in both components of SCR is shown using however other shapes of bodies with different conductivity values. The Im(SCR) are theoretically the resulting component from the conductivity changes in bodies to be analyzed [3]. It was possible to follow the evolution of the Im(SCR) until approximately 4 cm above where no changes were seen. The minimum measurable Im(SCR) was ~1.3E-6, corresponding to the measured standard deviation limit of 4 μV.

In the figure 6 is presented in logarithmic scale the Im(SCR) function of the sensing coil for the same bodies, during an angular sweep of the sensors. The sensing coil near the object was moved from position 225º to 315º (angular positions are marked in figure 1).

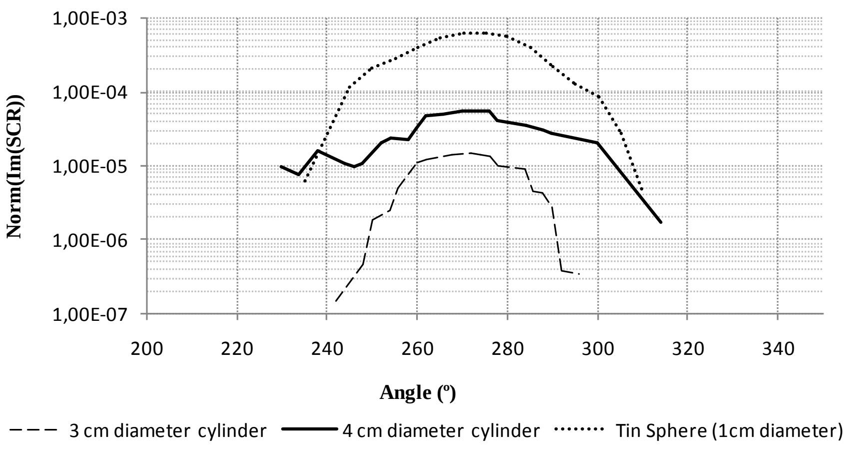

Fig.6 – Im(SCR) angle profiles for three conductivity bodies, placed in the center of the body plate.

Oscillations can be seen in all the 3 acquisitions, especially in the 4 cm diameter cylinder. The shown values were calculated taking into consideration a calibration where residual ***V'*** is obtained for each position and then subtracted to each acquisition. Hence, although this setup assures smaller variations of the residual field, inaccuracy of the positioning system is yet a possible source for these oscillations. Another possible source of errors is the small residual signal drift that was detected during calibration and acquisition stages due to thermal effects.

It can be seen that the 270º angular position and the 0 cm displacement of the figure 5 should have the same value. In Table 1, the values for the 0 cm displacement values from figure 5, the 270º position from figure 6 and an analytical approximation of the Im(SCR) value presented in [1] for centered cylindrical bodies with the z axis horizontally aligned with the source coil axis are compared.

Body Under Test	**Analytical Im(SCR) Approximation**	**Experimental Im(SCR) in 0 cm position from Fig. 5**	**Experimental Im(SCR) in 270º angular position from Fig. 6**
3cm diameter cylinder	-1.0E-5	-1.7E-5	-1.4E-5
4cm diameter cylinder	-4.1E-5	-3.0E-5	-5.5E-5
1cm diameter tin sphere	-4.5E-5	-5.2E-4	-6.1E-4

Table 1 – Comparison between experimental and theoretical Im(SCR) values, for centered bodies and aligned source and sensing coils.

Note that the analytical values are just an approximation of the expected experimental result: firstly, the bodies analyzed here are cylinders with vertical axis and one of the objects is a sphere. Secondly, the analytical approximation assumes that the radius of this cylinder is much smaller than the space in analysis, which is not completely true in our case.

Experimental values associated the 3cm diameter cylinder Im(SCR) with are similar and both are relatively close to the magnitude of the analytical approximation. The same happens with the 4cm diameter cylinder Im(SCR). The tin value has a disagreement between experimental and analytical values. It could be justified by differences between the tin conductivity model and the real conductivity value, not known. It could be also justified by the different shape assumed in the analytical approximation.

In all cases, the disagreements between the two types of experimental data can only be explained by the mentioned oscillations.

IV. Conclusions and Further Work

We have presented a MIT setup that has inherent cancelation properties that are kept in moving sensing coils, allowing the cancelation of ***V***. Preliminary acquisitions were made, showing its feasibility to be used in angular sweeps around the body.

The test presented in figure 5 showed that the acquisition system was able to measure Im(SCR) values down to 1.3E-6. Im(SCR) values acquired during the angular sweep of the sensors were compared to numerical approximations and to static acquisitions, presenting a good level of agreement.

It became clear that the correct alignment of each component of the system is a critical feature. Also, the small drifts are troublesome since moving sensors acquisitions can’t be effectively used if stationary conditions are not achieved.

A significant difference between the presented setup and the standard one is that it is not possible to acquire angle sweeps bigger than 180º, since information will be repeated. Its impact is being studied in terms of the inverse problem reconstruction.

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] S.Watson, A.Morris, R.J.Williams, H Griffiths and W Gough, “A primary field compensation scheme for planar array magnetic induction tomography”, Physiol. Meas., no. 25 (2004) 271–279.

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

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

[5] P. M. Ramos, A. Cruz Serra, “A new sine-fitting algorithm for accurate amplitude and phase measurements in two channel acquisition systems”, Measurement, Vol. 41, Issue 2, February 2008, pp. 135-143.