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Magnetic Induction Measurements with a Six Channel Coil Array for Vital Parameter Monitoring

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Abstract— **Vital parameter monitoring on neonatal intensive care units is essential but very stressful for patients during daily routine care. For contact-less monitoring of breathing and heart activity, magnetic induction measurements are applicable in research scenarios. For monitoring both vital parameters in newborn intensive care wards, we developed a Multi Channel Simultaneous Magnetic Induction Measurement System (MUSIMITOS2+). In this article we now evaluate the technical requirements of a coil array for vital parameter monitoring and finally present a multichannel coil array with 6 excitation and measurement channels combined as axial gradiometers for the specific measurement scenario. This array will be stored underneath the child. As a test case we will present data of a animal trial with the described coil array and the measurement device MUSIMITOS2+.**

I. INTRODUCTION

Monitoring of breathing rate and heart activity in incubator care of newborns can be very stressful for these patients. Since the skin of these babies is not as resistant as the skin of adults, glued electrodes as well as the change of these electrodes lead to stress and illness of the patients. A fully contact-less monitoring would help to decrease these stress situations. Another scenario is the monitoring of patients with third-degree burns where no glued electrodes can be applied. Magnetic induction measurements enable the cable-free monitoring of breathing and heart activity. However, there are no devices available on the marked. Instead, several research groups use the technology for vital parameter monitoring or brain edema detection.

For the specific scenario of monitoring newborns inside an incubator, we previously developed two measurement devices [8] and [2] which can be used with external coils for vital parameter detection. In this article, we investigate the technical requirements of a multichannel coil array which, could be stored underneath the newborn and is compatible to the existing measurement hardware. For the evaluation, we use CST finite element software. The multichannel approach is necessary for a proper coverage of the measurement area which could help to decrease movement artifacts and may enable spatial detection of breathing diseases. We will present a technical prototype of a six-channel coil array and end up with first results of an animal trial with a two days old pig representing the newborn.

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II. BASICS

A. Magnetic Induction Measurements

Figure 1 shows the principle of the measurement technique. A homogeneous time variant magnetic field induces a voltage in an electrical conductive medium. In our case the medium is the human body. Due to breathing and heart activity, the electrical conductivity change over time and thus, the driven eddy current is time variant as well. These

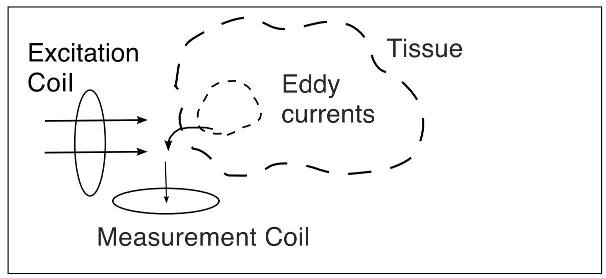

Fig. 1. Magnetic Induction Principle

modulated eddy currents reinduce a second magnetic field which could be measured with the additional measurement coil.

B. Compensation Techniques

For the measurement hardware we use, it is important that only the reinduced fields are measured and not the excitation field which is in the range of approximately 10^6 stronger. Thus, it is necessary to implement a compensation technique at the measurement coil. In literature, several approaches are known. By arranging two coils orthogonal together (e.g. [4]), the excitation coil does not induce an electrical field into the measurement coil. With a combination of two measurement coils as a (Planar/Axial)-Gradiometer (e.g. [5] and [6]), the measurement coils could be arranged in the same orientation as the excitation could but without measuring the excitation field. However, this requires an additional measurement coil and thus more space and volume of the array. The last mentioned compensation technique is the usage of a backoff-coil (see [3]). The excitation field is measured with a separate coil and the recorded voltage is subtracted from the voltage record at every other measurement coil. However, with MUSIMTOS2+ we cannot use this technique because of the implemented hardware design.

III. ARRAY ANALYSIS

For contact-less vital parameter monitoring with magnetic induction measurements, some requirements are important:

- coverage of the whole bed
- Induction into the body
- detection of very small reinduced fields
- small space between measurement points

However, using multiple measurement points/coils solve the first point. Because of the orientation of the emitted field vectors of an excitation coil, the best orientation for inducing fields into the body, the coil area must be in parallel with the body surface. In every other orientation, the excitation field will only stripe the body. For an evaluation of the next point, it is important to know the approximate position and orientation of the induced eddy currents. Analytically and with a simple FE model, it has been solved in [4] and [7]. In this article, we run finite element simulation with a neonatal model (published in [1]) to investigate the currents in a thorax of an infant child with a more complex structure (lung, heart, spine, ribs and surrounding tissue).
For the simulation, we used an excitation coil (diameter = 30mm) oriented in parallel to the body (dorsal position, X-Z-area, compare figure 2) and investigated the orientation of the eddy currents in X-, Y- and Z-direction.
Figure 3 presents an example of such a simulation. The

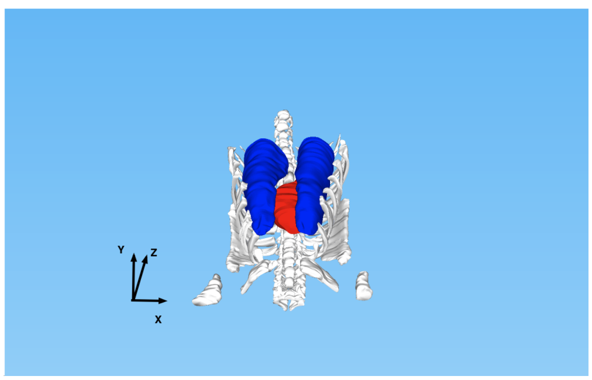

Fig. 2. FE model with coordinate system.

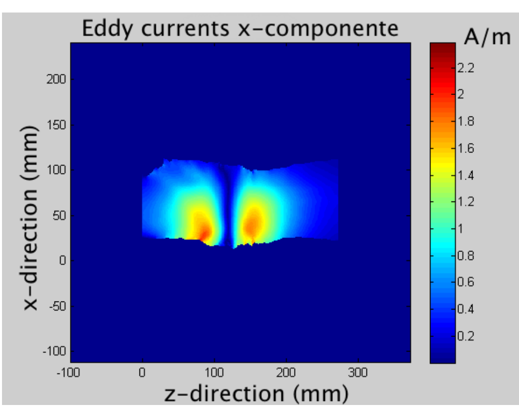

Fig. 3. Simulated eddy currents in a neonate thorax. X-component of current shown. Excitation coil current 3A. View from above.

results for the Y- and Z-component are shown in 4 and 5 All these figures are slices of the thorax region. The shown current density in the figures are calculated for that specific

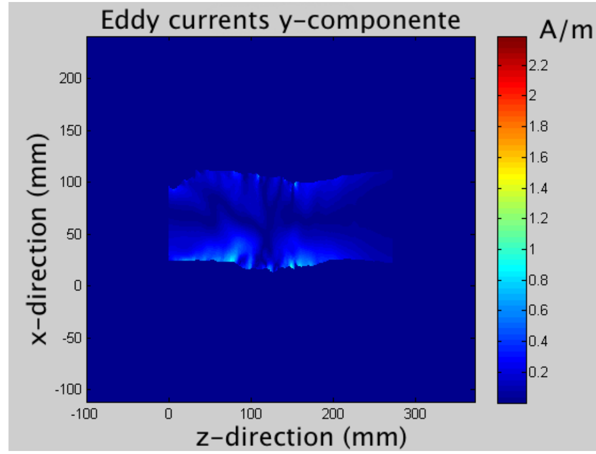

Fig. 4. Simulated eddy currents in a neonate thorax. Y-component of current shown. Excitation coil current 3A. View from above.

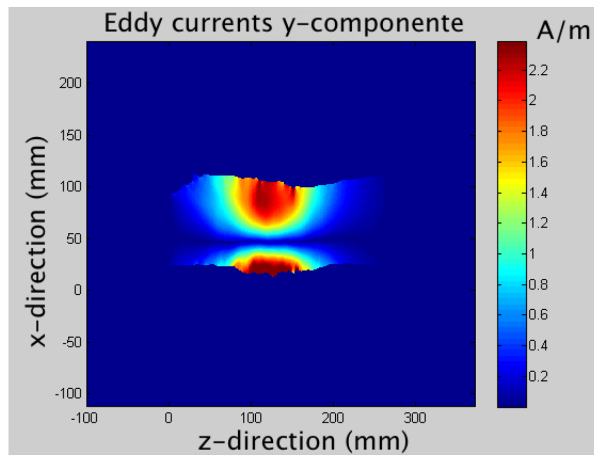

Fig. 5. Simulated eddy currents in a neonate thorax. Z-component of current shown. Excitation coil current 3A. View from above.

slice. The figures show, that the induced eddy currents basically flow in X- and in Z-direction, which lead to a loop in the surface parallel to the excitation coil. In [4], circular currents were calculated in a block of homogeneous tissue. Thus, the organs (lung, heart), as well as the bones and the spine have no strong influence of the directions of the eddy currents. Here, they mainly follow a circular shape as well. Since the reindexed fields of these eddy currents are in the same direction as the excitation fields, a coil array with is sensitive here is required. Thus, a coil array with orthogonal compensated coils comes behind setups with the measurement coil in parallel to the excitation coil. These setups are axial- and planar-gradiometers. The necessary ground area for planar-gradiometers is bigger than for axial-gradiometers due to the needed space for the measurements coils. Thus the possibility to combine several planar-gradiometer close together as an array is limited. Therefore, we choose axial gradiometers for the presented coil arrays. The thicker setup compared to planar-gradiometers is less a problem because the whole array can be placed in the X-ray tray of the test-incubator underneath the child.

IV. DEVELOPED COIL ARRAY

A computer model of the developed coil array is shown in Figure 6. With the screws on top (painted in blue for one

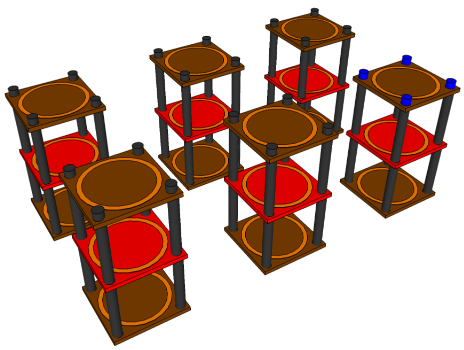

Fig. 6. Computer model of a 6 coil array. Excitation coils in the center painted in red.

gradiometer)m it is possible to calibrate the compensation. The pre-amplifiers for the gradiometers as well as for the excitation coils are connected with twisted pair cabling. Thus, the whole electronic parts are outside of the magnetic fields. The technical specifications are shown in table I. Each excitation coil is driven with an individual excitation

TABLE I

SPECIFICATION OF THE COIL ARRAY

Description	Dimension
diameter of coils	30mm
distance of coils within gradiometer	30mm
distance of gradiometers	20mm

frequency. Thus, it is possible to detect the pathways from every excitation coil to each measurement gradiometer. This enables recording of 36 channels in total at the same time.

V. RESULTS

The developed coil array was tested in an animal trial with four pigs in the age of two days. The age corresponds to a human neonate in the 36th week. Flow reference and a photoplethysmogram were recorded simultaneously to the magnetic induction measurements as reference signals. The coil array was stored underneath the pig in the X-ray blade of the incubator (distance to the pig approximately 50 mm). Each animal was ventilated with artificial ventilator. Figure 7 presents a snapshot of these measurements and show the magnetic induction signal together with the flow reference. The marked dots are the peaks of each data stream. As shown, it is possible to recognize breathing. The maxima of the flow and the magnetic induction signal are 90-degree phase shifted. This has a technical reason. The flow signal corresponds to the air stream flow and the magnetic induction to the lung volume which are both 90-degree phase shifted. However, different from adults, detection of heart activity in

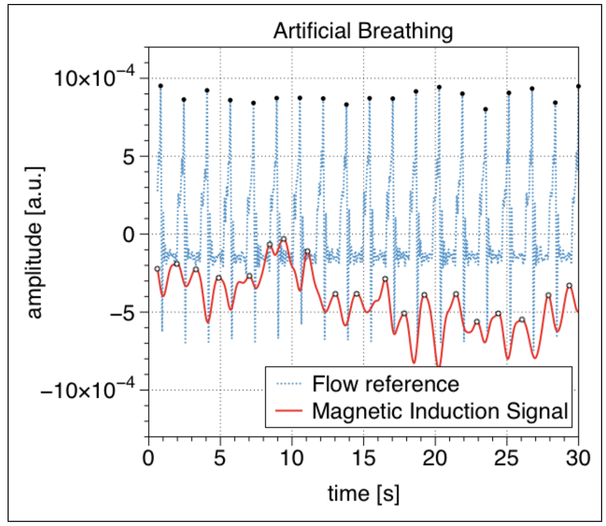

Fig. 7. Sample plot of animal trial 3

piglets still is a problem due to the very small reinduced fields which correspond to heart activity.

VI. CONCLUSIONS

In this article, we evaluated the eddy currents induced in the thorax region of a newborn with FEM simulation technology. Based on these results, we developed a six-channel coil array for vital parameter monitoring. First tests were performed during four animal trials, which demonstrated the overall functionality without an investigation of spatial resolution for breathing detection. This point and the proper detection of heart activity are part of ongoing research. Here, we will test the array with a lung phantom of a neonate and in a bigger animal trial series.

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