34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

A Neonatal Thorax Phantom for Contact-less Magnetic Induction Vitalparameter Monitoring

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***Abstract*— For contact-less monitoring of breathing and heart activity, magnetic induction measurements are applicable. For research and the development process of hardware and algorithms for parameter extraction, test cases are computer simulations, animal trials and, at the end, human trials. However, in the first development processes human trials are not suitable due to ethical reasons. Simliarly, animal trials may not be reasonable for only testing different amplifier approaches or basic testing of new coil configurations. There, computer simulations are the only available benchmarks but not suitable for every problem. In this article, we present a neonatal thorax phantom for emulation of lung and heart activity for magnetic induction systems as a test platform.**

I. INTRODUCTION

Development of complex magnetic induction measurement system for vital parameter monitoring require test cases for the hardware, software as well as the algorithms for source separation of breathing and heart activity related information in signal processing. General functionality could be tested with lab test fixtures. The signal quality of the signal generation circuit could be tested with a scope or spectrum analyzer for instances. General evaluations of coil arrays could be solved with finite elements computer simulations. But for tests of the whole device or software, tests on humans are crucial. Since we are are aiming at monitoring newborns inside an incubator, this is a tough scenario for safety reasons. However, in early stages of the development process it is ethically not possible to measure on neonates. For these tests, animal trials are established. There, the whole system could be evaluated under real conditions with real artifacts and real biological signals and processes.

For testing amplifiers, basic coil settings or different algorithms, however, these trials are not possible due to the same ethical reasons. Here, a new test fixture is required.

In this article, we will present a thorax phantom with breathing and heart activity functionality suitable for magnetic induction measurements with the focus on vital parameter monitoring. Sizes and volume of lungs and heart of the phantom are in the same size as a four weeks old baby. Minimum and maximum breathing and heart rates are suitable for emulating the vital parameters of a newborn, too. After the system description, we show the overall functionality of the phantom on test measurements with a magnetic induction measurement system we developed for vital parameter monitoring (see [1]).

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II. BASICS

A. Magnetic Induction Measurements

The contact-less monitoring of vital parameters with the magnetic induction technology is based on an induced voltage in the human body by an homogenous magnetic excitation field. Due to different electrical conductivities of the biological tissue over time due to breathing and heart activity (electrical good conductive blood pumped through the heart and less conductive air in the lungs), the generated eddy currents are time-variant as well. Because of the local distribution of the heart and the lungs, it is spatial-variant as well. With the measurement coils, it is possible to detect the reinduced fields, which are driven by the eddy currents. Signal analyzes then provide monitoring of breathing or heart rates for instances. By using several measurement coils it is possible to cover the measurement area and to detect the distributed reinduced fields for with spatial resolution.

B. Requirements

For defining the requirements of a phantom, it is necessary to take a look on the biological processes, which influence the magnetic induction measurements:

- Separate excitation techniques for heart and lung activity (individual rates required)
- Ventilation of the lung with air
- Pumping conductive medium representing the blood through the heart equivalent
- Sizes and volume according to size and weight of a newborn
- Breathing frequency of 0 to 120 strokes per minute (according [6] and [7])
- Heart rate of 0 to 180 beats per minute (see [2] and [4])
- Emulation of tissue conductivity of lung and heart

In the next paragraph, we will explain how these points are solved in the developed thorax phantom.

III. DESCRIPTION OF PHANTOM

Since we could use an external air source feeding the device, filling of the lungs with air could be implemented with electrical controlled valves for inspiration and expiration (complete block diagram of pneumatic schematic of the lung part is presented in Figure 1). After a main pressure control valve, which reduces the air pressure from the source to a working pressure of 0.6 bar, an electrical controlled valve manages the IN and OUT flow to the lungs. There, a separate throttle valve at each lung enables simulation of lung pathologies such as obstructions or a complete

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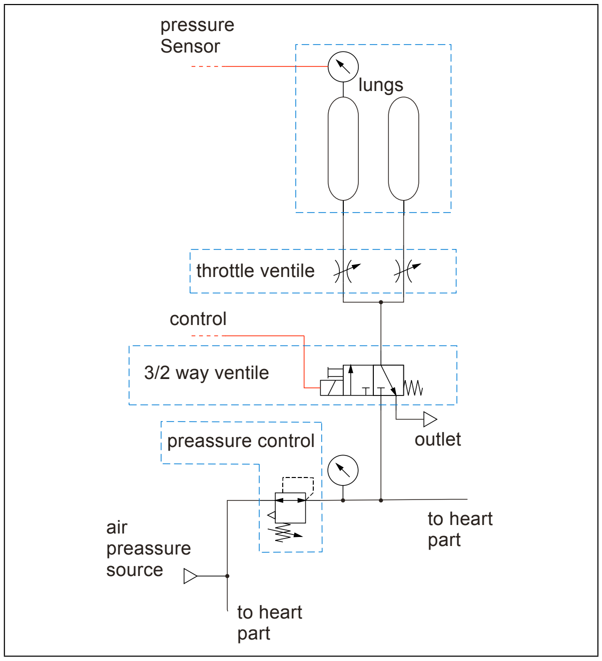

Fig. 1. Block diagram of pneumatic part of the lungs

blockade of the airways. For preventing burst of the lungs, a pressure sensor is connected to the lung balloons. As lung material, we used bicycle inner tubes. These are cheap and the compliance is ideal for emptying of the lungs without the need of an additional source. The surrounding medium is saline with the electrical conductivity of normal tissue. The size and volume of the water tank is equal to the size and volume of the thorax of a four week old newborn (shown in Figure 2).

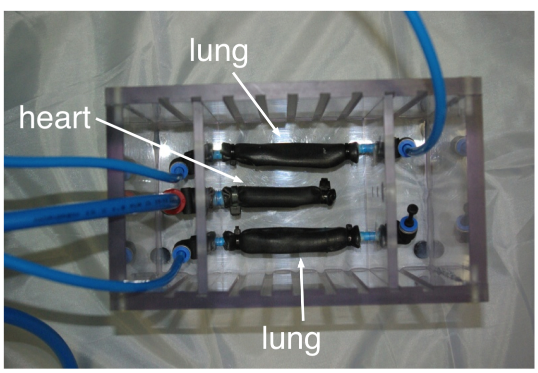

Fig. 2. Thorax model with lung and heart

According to literature [2], [3] and [5], the specifications of the simulated organs are presented in Table I. The heart in the model is made of bicycle inner tube as well, but here, we used saline (endowed with the electrical conductivity of blood) as filling medium and not air. At high emulated heart rates, the heart balloon will not empty proper by its own. Thus, an external vacuum source is needed for supporting the emptying process. The block diagram of the heart part of the phantom is presented in Figure 3. The filling of the heart is realized with an electrical controlled valve and a medium

TABLE I

SPECIFICATION OF THE COIL ARRAY

Description	Dimension
Lung length	70 mm
Heart length	30 mm
Heart volume difference (full to empty)	20 ml

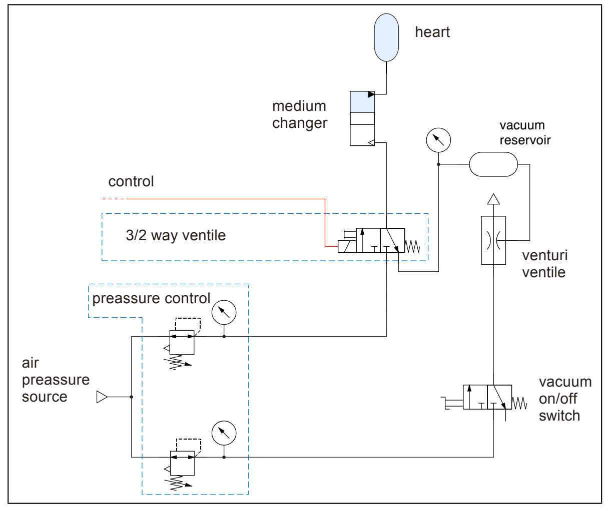

Fig. 3. Block diagram of pneumatic part of the heart

changer. In the changer, the air pressure pumps saline into the heart balloon. For supporting the emptying of the heart, a vacuum reservoir is connected to the medium changer over the same electrical valve. The vacuum is generated with a venturi injector.

The whole system is control by a MSP430 micro controller. It enables external control via a computer and USB connection or via a display for setting heart or breathing rates and the filling levels. The lung pressure is measured with the micro controller as well. The lung and heart phantom together with the control device are presented in Figure 4.

Fig. 4. Lung and heart phantom connected to frontend control device with display

The blue bottle in the photo is the medium converter, which can be filled with saline.

IV. RESULTS

A. General Analyzis

For the general test cases, we use the MUSIMITOS2+ magnetic induction measurement system in combination with a six-channel axial coil gradiometer underneath the thorax model. The setup is shown in Figure 5.

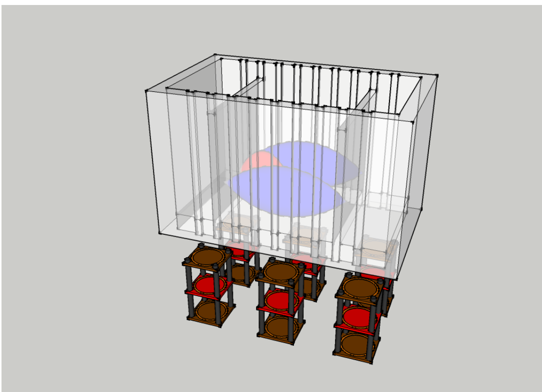

Fig. 5. Model of measurement setup. Coil array underneath thorax phantom.

For the first test, we choose a breathing rate of 15 beats per minute = 0.25 Hz. The pneumatic part for the heart was not activated during this test. The Fast Fourier Transform (FFT) spectrum of one measurement signal is presented in Figure 6. As shown, the breathing rate is clearly visible in

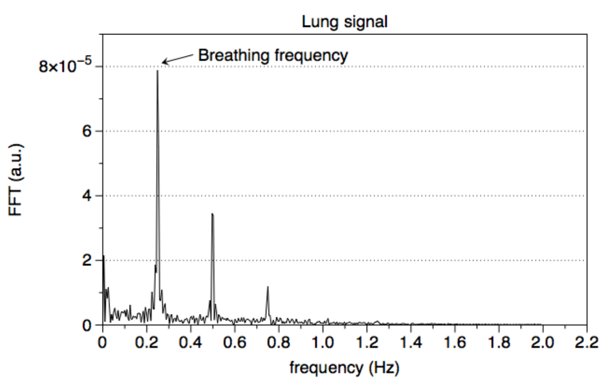

Fig. 6. Lung signal of phantom. Breathing rate: 0.25 Hz including second and third order harmonics.

the spectrum. The plot for a test only with a heart signal (heart rate: 40 beats per minute = 0.67 Hz) is presented in Figure 7. As for the breathing trial, the heart related signal is visible in the spectrum as well. However, in both figures the harmonics are visible, too, which corresponds to the recorded data in real measurements on humans.

Results for a test with activated breathing and heart signal are shown in Figure 8. There, both signals are present as a peak. However, the magnitude of the heart related peak is much the same as the harmonic of the breathing related

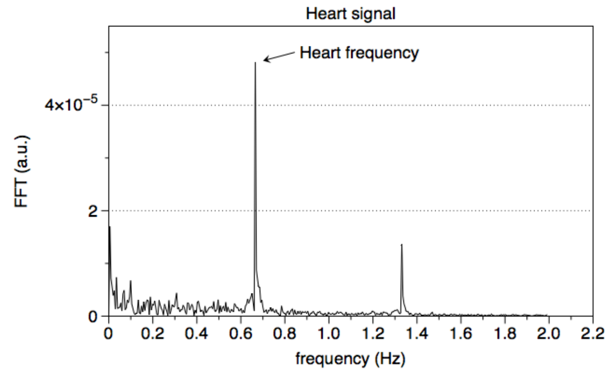

Fig. 7. Heart signal of phantom. Heart rate: 0.67 Hz.

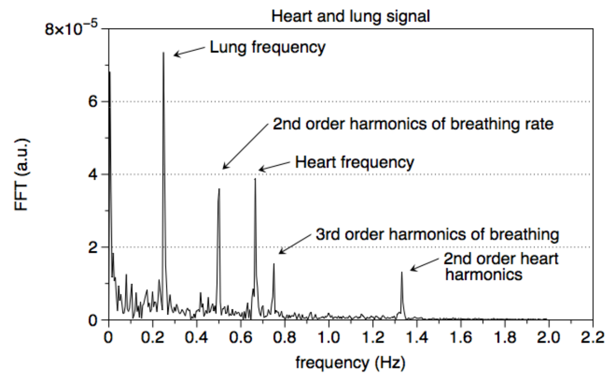

Fig. 8. Heart and lung signal of phantom. Heart rate: 0.67 Hz, Breathing rate: 0.25 Hz.

signal. This can be found in real data as well. But there it could be possible that the heart rate is within the same frequency as the breathing related harmonic. Thus, detection of both parameters only based on the spectrum is not always possible.

B. Spatial resolution

One test case with the developed phantom is the investigation of the spatial resolution of a given coil array. Emulating a blocked lung is realized with the throttle valves in front of the lung balloon. Performing the same test in an animal trial with the same accuracy over several measurements is much more difficult. Thus, the developed phantom enables an easier-to-handle test platform for this kind of tests. However, this can only be part of the ongoing research. The final coil array must be tested under real conditions in an animal or human trial. For the test on spatial resolution, we choose a breathing rate of 15 beats per minute = 0.25 Hz. The heart part was not activated during this test. We used the same coil array an measurement platform as for the test presented above. For investigation of the spatial resolution, we performed three measurements. One with both lungs open and the others with a blocked lung (left or right). Figures 9 and 10 demonstrate that the chosen coil is sensitive only for conductivity changes of one lung. If the other lung is ventilated only, the recorded data show no peak in the spectrum. However, if both lungs are ventilated, the magnitude of the peak is stronger than for the case the lung is ventilated which is in the sensitivity area of the coil. This could be some effect of the driven eddy currents since the path is influenced by both coils.

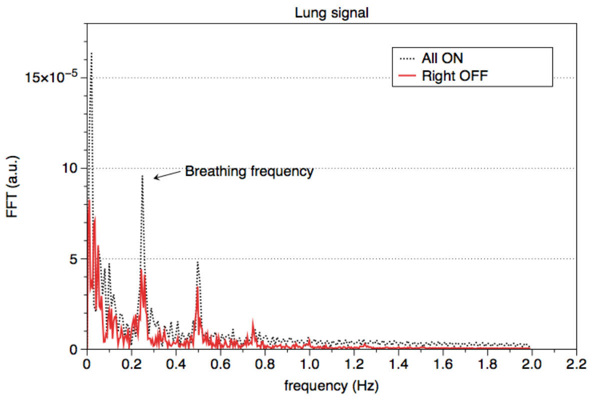

Fig. 9. Both lungs activated compared to right lung deactivated.

Since we did not run trials with animals (yet), we cannot compare these results with real data. However, this is addressed as one next step but not for evaluating the phantom only, it is interesting for the coil array development in the project group as well.

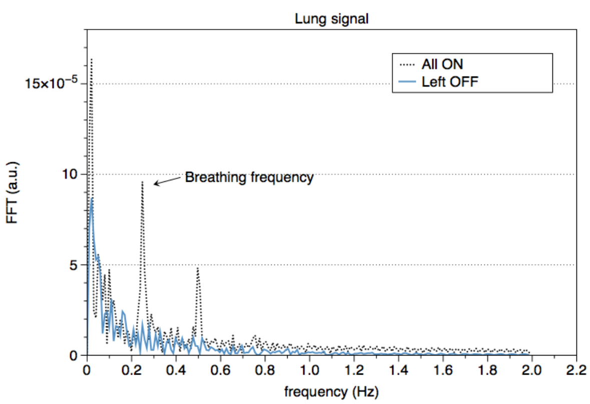

Fig. 10. Both lungs activated compared to left lung deactivated.

V. CONCLUSIONS

In this article, we described a phantom for emulation of breathing and heart activity in scale of a neonate. After the system description, we presented the functionality of the phantom with sample measurements with a magnetic induction measurement system for vital parameter monitoring. We could demonstrate that the phantom is suitable for spatial resolution simulations as well. We will validate these results in an series of animal trials in the future. Next development step for the phantom will be the integration of a new firmware which enables the emulation of special breathing patterns e.g. asthma. Then, we can evaluate our measurement setup for a test of other neonatal lung pathologies.

ACKNOWLEDGMENT

The authors gratefully acknowledge the German Research Foundation (DFG) for supporting this project (DFG LE 817/8-1).

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