Experience from a Trial Study of Getting Foucault Cardiograph Signal from Salty Water Medium

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***Abstract*—To study the feasibility of using Foucault cardiograph (magnetic induction cardiograph) in intelligent life jackets as the sensor of heart activity, a trial study has been performed. Sensitivity of the sensor attached to a male test person who stood in salty water, was studied for several salinities (7.7-33‰). Composition of the experiment has been tested and preliminary data for feasibility assessment have been recorded. Due to shunting effect of salty water, sensitivity of the Foucault cardiograph to heart contractions decreases towards zero with the salinity growth. Emerging of cardiac-synchronous signal in the device which is put into salty water, by another concurrent mechanism was found. Without further development, the FouCG method may have prospect to be used for application in life jackets at salinities up to 20 ‰. Probably, the development of sensor and using proper signal processing may extend detection of heart activity by this technology to a wider range of working conditions of the life jacket.**

Keywords*—*heart activity; cardiography; detection; magnetic induction; eddy currents; sea water; life jacket

I. Problem and Objective

In humans' health state monitoring, especially when people work on the ocean or a sea, there is necessity for tracking the presence of their heart activity while being or drowning in the sea water. This task has initiated the search for a proper sensor for detection of the heart activity in humans who are in salty water medium. One of the systems under consideration could be the Foucault cardiograph [1]. Still it was questionable whether the device could give reliable signal if it was surrounded by a highly conductive medium like the ocean water.

Foucault cardiography (FouCG, aka *magnetic induction cardiography*) is a non-invasive method for continuous and long-lasting tracking of the mechanical activity of the heart. It is based on probing the heart region with electromagnetically induced high-frequency eddy currents and simultaneous measurement of corresponding loss resistance of the inductor [2].

The objective of the present trial study was to get data about the ability of the FouCG sensor to detect heart activity, when it is attached to a person being in water having salinities ranging from the salinity of the Atlantic Ocean (32…36‰) down to low salinities typical to the Baltic Sea (below 10‰).

II. Equipment

For the experiment, a special exemplar of self-oscillator type Foucault cardiograph [3] having 5 levels of signal amplification (K_U = 870, 4300, 20800, 102000, 500000) was built. Switching the amplification was performed by reed switches that were activated through the sensor wall by a small strong permanent magnet. The sensor worked with the probing current frequency of 8 MHz.

To avoid the occurrence of intensive eddy currents in the water surrounding the FouCG sensor, its back and lateral sides were surrounded with a volume of polystyrene foam which was itself covered with a water-proof layer (Fig.1).

The single-loop inductor coil of the sensor had a shape of circle (outer diameter 138 mm), made of copper a tube (outside diameter 6 mm). Its midplane was located at a distance of 7…9 mm from the rear surface of the sensor (which touches the thorax). The sensor was inserted into a rectangular screening box represented in Fig. 1.

The sensor was powered from a battery; the signal recording system was powered from the mains (~230 V) through a *Noratel IMED$_e$ 2000* medical isolation transformer. Whole system had been tested for electrical safety according to the rules of IEC 60601 standard.

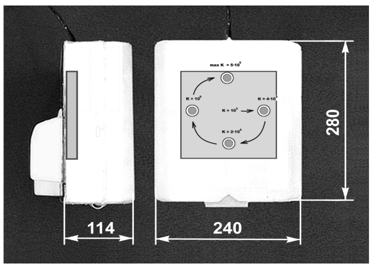


Fig. 1. The covered FouCG sensor. The sensor itself, mounted into its screening box, is marked by grey rectangles located inside the covering. In the front view, the holes for amplification switching magnet are visible. Dimensions are expressed in millimetres.

The study was sponsored by the ELIKO Technology Competence Centre in Electronics-, Info- and Communication Technologies, Estonia.

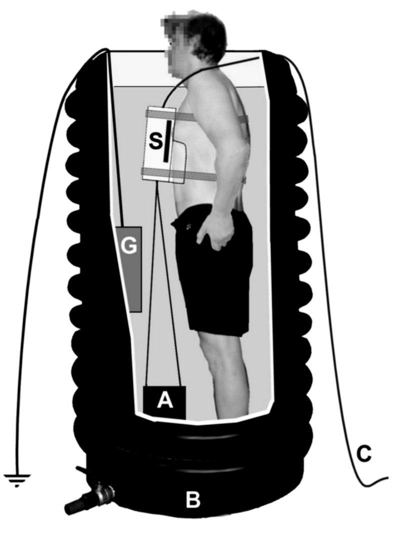


Fig. 2. Set-up of the experiment. S – the covered FouCG sensor, sensor itself mounted into its screening box is marked by a dark rectangle; G – grounding electrode; A – anchor; B – plastic barrel; C – signal cable.

Another important part of the equipment was the water container used for the tests. A custom-made plastic barrel (Fig. 2) with an inside diameter of 995 mm and height of 1880 mm (volume 1.4 m3) was used. It was equipped with ladders and a standing platform, the height of the platform was individually adjusted to fit the test person.

The sensor in its covering was attached to the thorax of the test person with two elastic belts; the covering was anchored to the bottom of the vessel. To minimize the mains interference, the liquid content of the barrel was electrically grounded.

III. Experiments

In the experiments, FouCG signal from a single male test person (healthy, 38 years, 91 kg, 186 cm) was recorded at the following salinities of the water: 7.7 ‰, 13 ‰, 18 ‰, 22 ‰, 26 ‰, 29 ‰, 33 ‰.

The different salinities were achieved by mixing tap water with ordinary table salt. A water sample was taken from the barrel for each of the salinities and analysed afterwards. The salinity was estimated using the evaporation method. 80 cm^3 of water were taken for this analysis from each sample. The weighing was carried out using electronic scales Kern EMB 1000-2 having 10 mg least digit value.

Signal from the test person was recorded at standing still with normal breathing. The signals were digitized with a sampling rate 250 Hz using a NI USB-6215 converter and recorded to files by NI LabVIEW.

IV. Data processing and InterpretatiON

The recorded raw signals were filtered by smoothing filter for 50 Hz noise removal. An unexpected complication appeared during their analysis: the surface waves of the water in the barrel caused oscillations of the signal, among which sometimes was uneasy to distinguish heart pulsation. Still calculations made according to [4] suggested that the frequency of the first harmonic of those oscillations, for the depth of water having the value like the depth in our barrel, should be below 1 Hz. This has led us to use spectral analysis for the processing of the data. Using MATLAB software, power spectra of the signals were calculated and smoothed.

Examples of the recorded signals and their power spectra in the interval 0…5 Hz, sufficient for the representation of the three first harmonics of the heart-originated signal, are presented in Fig. 3. In the Fig.3 (a), the right graph shows the power spectrum of the signal which was recorded at ordinary houseroom conditions (i.e. “in air”). The spectrum contains three perfectly identifiable peaks of the cardiac activity. The spectrum achieved for this case was chosen as the reference one at the spectral analysis.

To present all the recorded signals in the Fig. 3 independently of the used amplification, the values of the recorded signals have been scaled back to the Foucault cardiograph’s detector output voltages.

To enable visual comparison of the power spectra graphs, the power density in each of them was normalized by dividing it to its maximum value. Values of the corresponding scaling factors ($Scale_1$=1 for the reference, $Scale_2$ for the current salinity case) have been printed in the figures.

It is evident that the cardiac-originated oscillation is present in all the signals presented in Fig.3. The task of comparative evaluation of the strength of FouCG signal received at various values of the salinity has been resolved by comparison of sums of the peak values of the first three harmonics of cardiac origin in the power spectra. Thus, normalized comparative index of signal strength has been defined:

$$U_{rel} = \sqrt{\sum_{i=1}^{3} S(f_i) \Big/ \sum_{i=1}^{3} S_{REF}(f_{REF,i})}\ , \qquad (1)$$

where U_{rel} is the index of signal relative strength, $S(f_i)$ is the power spectrum density for the signal under estimation at the i-th spectral peak frequency f_i of the cardiac-originated oscillation. The quantities having index $_{REF}$ are the same ones for the reference signal. U_{rel} compares the signal strength by estimating the ratio of the r.m.s. voltages of the compared signals.

V. Results and Discussion

The signal relative strength indices U_{rel} have been calculated for the signals recorded in all the tested salinities. The results are presented in Fig. 4. Unexpectedly, at higher salinities, the index shows strengthening of the signal. This can also be seen in Fig. 3. One can see in Fig. 5, that there is actually only a low signal component with cardiac frequencies at the salinity of 26 ‰. Still it appears at higher salinities. The reason of this phenomenon is evident from the Fig. 4(d). It can be noticed that the polarity of the cardiac oscillations has been changed to opposite in comparison with the cases of lower salinities.

With the device that we have used, this has become visible at the salinity values higher than 18 ‰. Such phenomenon could be explained by the presence of two mechanisms of cardiac signal generation. One of them, the one being present

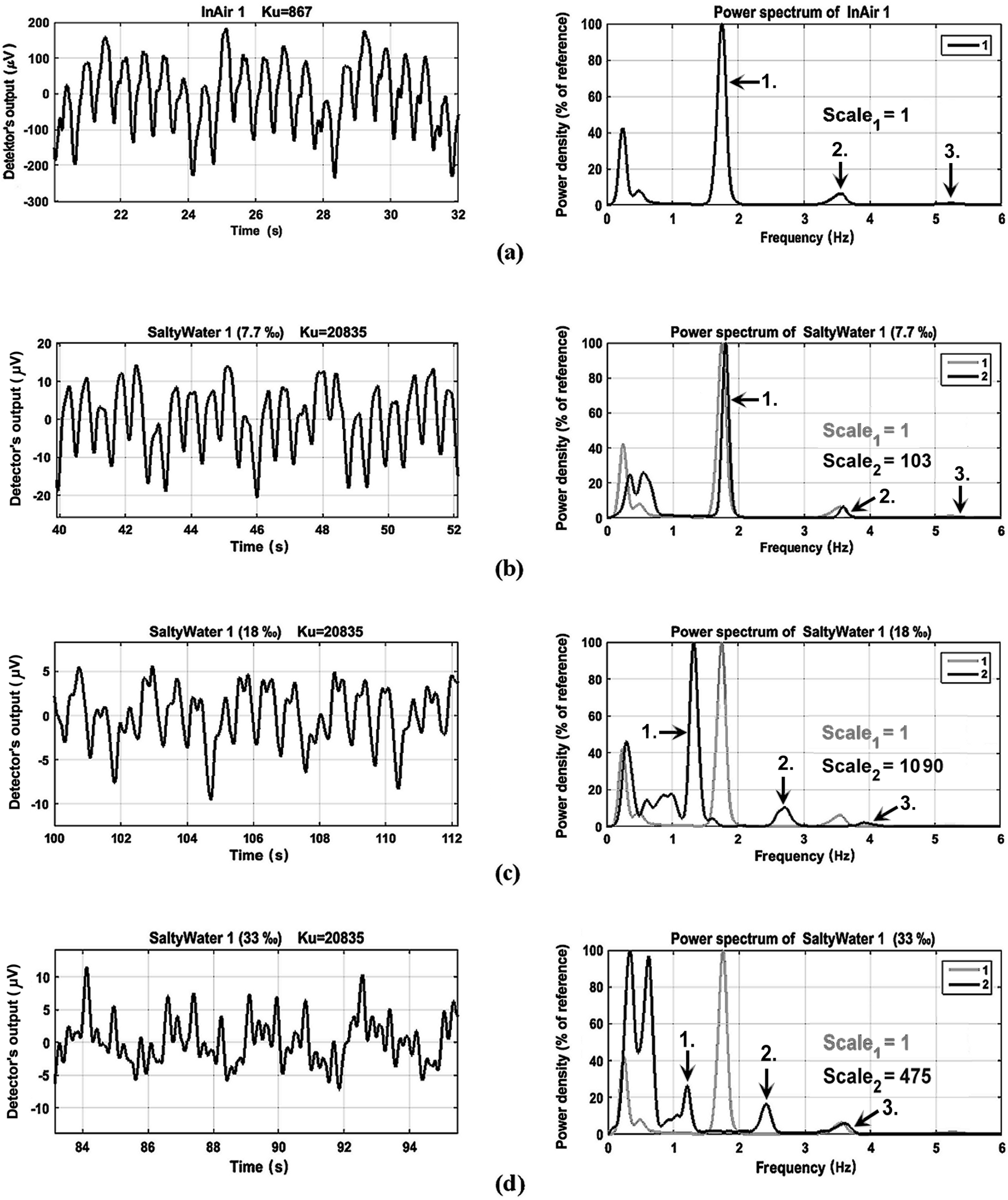


Fig 3. Examples of processed data. In the left column: excerpts from the filtered FouCG recording. In the right column: normalized power spectrum of the processes in the left. (a) – the reference case, recorded at ordinary houseroom conditions;
(b), (c), (d) – the cases of salty water with different salinities, the reference one being shown with grey colour;
numbered arrows indicate spectral peaks of cardiac origination.

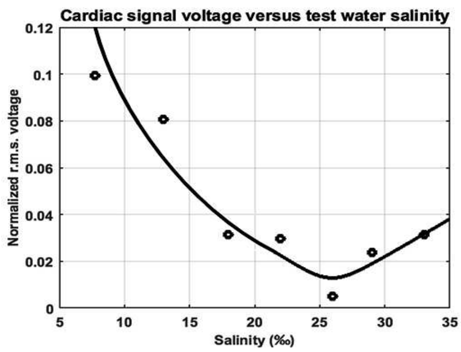
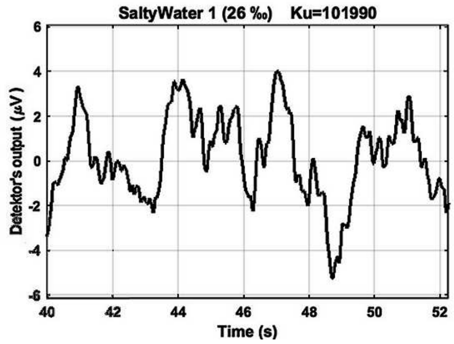
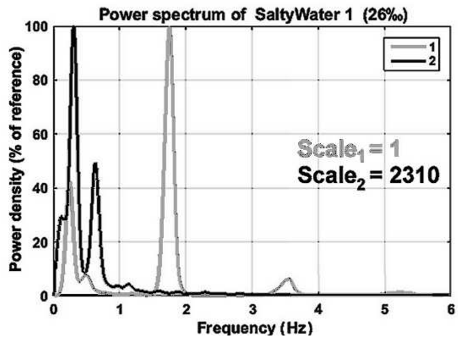


Fig 4. A result of the experiments: dependence of the cardiac signal relative strength U_{rel} on the salinity of the water. Notice the minimum at the salinity value of 26 ‰.



(a)



(b)

Fig 5. Demonstration of the absence of cardiac-orginated signal at 26 ‰ salinity:
(a) – time-domain signal consists mostly of oscillations having frequencies below 1 Hz and noise;.
(b) – power spectrum of the same signal has low level in the region of expected cardiac-originated maxima.

as the sole at "in air" conditions, decreases with the growth of salinity due to decreasing of the inductor's Q-factor with the growth of permanent losses in the salty water. The other mechanism must have a contribution which can even grow with salinity. Fig. 5 could serve as an evidence of approximate compensation of the two mechanisms near the salinity of 26 ‰.

The second of the two mechanisms could be due to pulsing of salty water content between the sensor and the thoracic front wall of the test person. Under the pressure of the thoracic front wall by the heart contractive motion, this water content would be modulated. When the wall moves forward, this water content diminishes. As the conductivity of the water at these salinity values is great, it has strong influence (of opposite sign compared to the first mechanism) onto the measured signal, while the heart's influence itself is even less due to the same reason. Thus the resulting impedance pulsing signal gets the inverse phase.

This phenomenon should be taken into account in the life jacket design.

VI. Conclusions

1. The equipment used in the experiments was sufficient to carry out the study and to make the conclusions presented below.
2. The surface waves in the barrel have complicated the analysis of the signal. Therefore, to better distinguish between the oscillations due to them and the cardiac-originated ones, it will be necessary to record another simultaneous signal of heart pulsing in the following research studies. Still at the possible exploitation, these oscillations might not be of importance due to greater wavelength in seas or oceans.
3. Possibility of emerging a cardiac-synchronous signal in FouCG device which is put into salty water, by another concurrent mechanism has been found in the study.
4. The FouCG method, without further development, may have prospect to be used for application in life jackets, at least at salinities below 20 ‰. In the corresponding design, the phenomenon referred to in Conclusion 3, shall be taken into account.
5. The influence of the sea waves onto the signal quality, if FouCG was used for tracking the heart activity, still needs further exploration.

Acknowledgment

The authors would like to acknowledge and thank the Tartu Health Care College and especially their Administrative Director Ermo Kruuse for kindly offering the room to carry out the experiments. We also thank Mr. Joel Vedru for his voluntary help at the measurements.

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