Physiological Measurement Based on Foucault Principle: Set-up of the Problem

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Abstract: The paper reviews the results of the investigation of a physiological measurement method based on the use of eddy currents to probe the object.

INTRODUCTION

Today a number of physical principles have been used for getting information of medical importance from the human body. Nevertheless a safe and comfortable method for long-term frequent watching of the interior of its most vital regions (e.g. thorax and abdomen) is urgently needed. We can state a principle that has been still of little use for this purpose: this is the measurement of electrical properties of the human body via the absorption of the energy of an alternating magnetic field due to the induction of eddy currents in it. As the phenomenon of eddy currents was first investigated by Léon Foucault, the principle can be named as *Foucault principle*. It can be used for technical imaging [1] but only few papers have been published on the use of this principle for physiological purposes [2].

METHOD

Let us imagine an elementary measurement system consisting of an inductor coil and a receiver coil placed in the neighbourhood of the object under observation. The electromotive force induced in the receiver coil will depend on the absorption of energy in the tissues. Such a method of measurement would have properties that differ from the properties of conventional methods (e.g. electrical impedance methods). The measurement based on the Foucault principle would be more convenient for watching the high-conductive object (heart) in low-conductive (pulmonary) media.

The experimental measurement system comprises a flat 4-turns coil with a 9 cm outer diameter. For preventing capacitive disturbances, the coil has an outer electrostatic shield. The latter is divided to several sectors to avoid short-circuiting. The coil together with a capacitor forms a parallel oscillatory circuit which is connected to a peak detector. The circuit is fed via a weak coupling by a remote generator tuned in resonance with it. The rf (30 MHz) voltage on the coil and the dc output of the detector are proportional to the Q-factor of the oscillatory circuit. In this simple arrangement the inductor coil serves simultaneously as the receiver coil. The absorption of rf energy in a bio-object near the coil induces a certain absorption resistance and modulates the Q-factor. Thus a signal, like the one represented on Fig. 1, is formed.

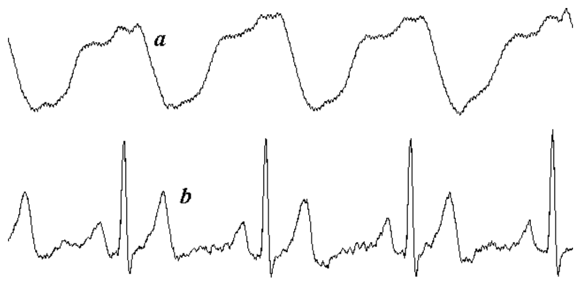


Figure 1. Time-dependent signals of heart contraction: *a* – signal received using the experimental system based on the Foucault principle, *b* – simultaneous ECG.

We experimentally studied the described phenomenon with the coil transducer positioned on the surface of a man's thorax in front of the heart. An equivalent series absorption resistance in the oscillatory circuit and its pulsation were calculated.

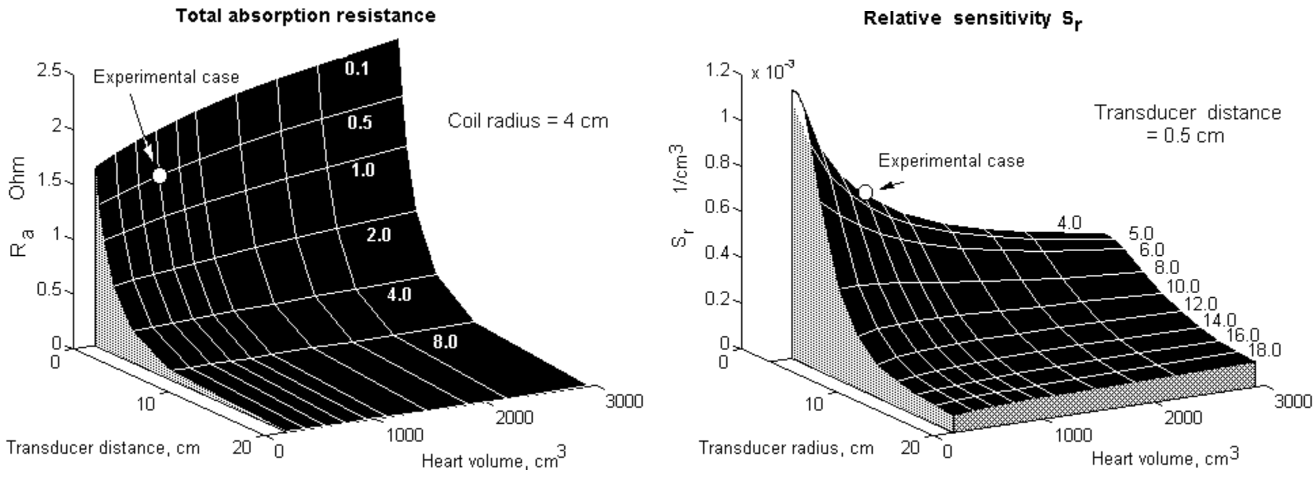
In parallel with the experimental investigations we applied theoretical considerations to study the properties of the new measurement system. A simple axial-symmetrical model of the thorax was presumed. A sphere representing heart was put on the axis of the model. It was placed in a co-axial cylinder having specific resistivity of the lungs. The front pole of the sphere was supposed to have a constant position during the heart contraction or dilatation. The dimensions of the model components were set according to human anatomy (the basic case: heart radius = 5.6 cm, front-to-back distance of the thorax = 24 cm, distance between the heart and the front surface of the thorax = 2 cm). The inductor coil was supposed to reside co-axially at definite distances in front of the thorax.

The specific resistivities of the regions were supposed to have only the active component and were set according to literature data (lung: ρ=1000 Ω·cm, heart: ρ=122 Ω·cm).

The numerical calculations were carried out on the assumption that the induced eddy currents were weak, therefore the reverse influence of the eddy currents to the magnetic field was ignored.

RESULTS

Fig.1.a shows a sample Foucault cardiogram of a man, recorded by described above transducer. The curve was received during breath-holding as breathing deeply affects the signal. Similarity of the Foucault cardiogram with the volume curve of the heart can be noticed.



a **b**

Figure 2. Examples of model-generated dependences of the measurement system characteristics on transducer position or dimensions and heart volume.

The experimentally estimated value of the equivalent absorption resistance for the case described above was R_a=(2.6±0.4) Ω. Its pulsations were ΔR_a=(92±30) mΩ, i.e. the pulsations magnitude was approximately 3.5% of the total absorption. Estimating the same quantities by numerical modelling, the case with the coil having the radius of 4 cm and positioned at the distance of 0.5 cm above the surface of the thorax was considered to represent the experimental situation. In this case the result of calculation showed 1.49 Ω total absorption resistance. This estimate is about 1.5 times less than the experimental result.

We numerically studied the total absorption resistance R_a for the character of its dependence on several geometrical parameters of the model. In the same manner we studied the absolute sensitivity of R_a to the heart volume change $S_a = \Delta R_a / \Delta V$ (Ω/cm³) and the relative value of the latter $S_r = \Delta R_a / (\Delta V \cdot R_a)$ (1/cm³), too. Some of the studied dependences are shown on Fig. 2.

Using the model-estimated value S_a=0.97 Ω/cm³, we got a rough estimate for heart volume pulsations for the experimental data: ΔV = (95±30) cm³, that is somewhat less than it should be for a normal heart.

DISCUSSION

The results obtained by model calculations reasonably agreed with the experimental data. This fact lends support to the general validity of the model and its calculation. A discrepancy between the results was expected as the model was considerably simplified. The main improvements required are: taking into account the influence of the eddy currents to the magnetic field, introduction of thoracic front wall into the model, more realistic description of heart movement.

Some conclusions were drawn from the calculated dependences of the R_a, S_a and S_r on the radius of the inductor coil and on the distance between the coil and the thoracic surface. As shown on Fig. 2a, the total absorbtion resistance has fast rise (and consequently a strong dependence on distance) at small distances. But at the distances greater than 3...4 cm this dependence gets weaker.

The transducer relative sensitivity S_r is nearly independent of the heart volume at a definite coil radius. In the case of transducer distance of 0.5 cm (Fig. 2b) the independence can be achieved at the coil radius of about 9 cm.

Some other interesting relations were noticed. A similar independence of the heart volume is obtainable with the relative sensitivity S_r at a distance of about 7 cm (if coil radius is 4 cm). Besides it is possible to achieve the volume-independence of the absolute sensitivity S_a of transducer. This feature refers to the cases with small coil radii (less than 4 cm).

We expect that the relations found, with certain distortions, will hold true in the case of real thorax, too, and they can be used at the design of the measurement system on the basis of transducer(s) like the one described above.

The results of the first studies suggest that new techniques for physiological measurements (e.g. in circulation) can be developed on the basis of the Foucault principle.

REFERENCES

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