- the inner diameter of the cylindrical housing is to be no less than 2 times greater than of the electrode inner diameter.
- the measuring electrode is to be equal to 200 mm.
- the length of the guard electrodes are to be no less than 2.5 times greater than of the isolation cable diameter.
- the gap between the measuring electrode and the guard electrode is to be minimal.

Thus, the research conducted has shown that change of water salinity affects the results of the cable linear capacitance control.

An optimal electrocapacitance transducer design was simulated by means of the Comsol Multiphysics 3.5a program. The design is considered to be optimal if β tends to 1.

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Simulation of cardiac electrical activity with electrocardiograph based on nanosensors

Abstract. The problems related to cardiovascular diseases are considered. The method to solve some of the problems has been proposed. We also consider a two-component Aliev-Panfilov model and the algorithm of the hardware- software complexes. The obtained results are presented.

According to World Health Organization (WHO), over 17 million people worldwide die annually from cardiovascular diseases (CVDs). Moreover, according to WHO, an estimated number of almost 23.6 million people will die from CVDs by 2030. In 2012, 1 million 232 thousand 182 people died from CVDs in Russia (Fig.1) [1].

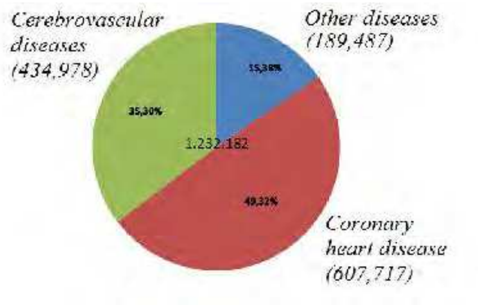

Fig. 1. WHO report on GCC for 2012

Electrocardiographic (ECG) method is a common method to examine the state of a patient's cardiovascular system in various medical institutions. ECG is referred to as the method of functional diagnostics with a quantitative evaluation of the research results. The first cardiographic research was carried out by the Scottish scientist Alexander Muirhead in the late 19th century [2]. A body is known to be a 3-D conductor. The cardiac activity results in electromagnetic field generation, which can be measured from the body surface. The field is constantly changing under heart excitation and characteristics of the field depend on the moving direction of the excitation wave passing through the heart. The analysis of the electromagnetic field allows us to consider the sequence of atrial and ventricular excitation.

Lots of companies are trying to solve this problem, but just some of them managed to succeed.

The analysis proved the absence of the hardware and software complexes for mass application (in departments of functional diagnostics and cardiology, in hospitals and clinics, in ambulances, as well as in private medical practice, and at home) to be used in a non-invasive detailed study of the heart by registering low-amplitude potentials of the heart from the surface of the human body without filters and cardiac cycle averaging. Such devices are presented in Table 1.

Table 1. Overview of the manufactures

Company's name	Number of leads	Signal level, μV	Frequency range, Hz	Cost
Geolink-electronics (Russia)	3	6	0.03–10.0	$7700
Rozinn (USA)	3	8	0.05–70	$11000
OXFORD (England)	3	5	0.05–100	$11400
NRTPU (Russia)	3–12	0.3	0-10000	<$1400
Davis Medical	3–12	2	0.05–60	$6500

Electronics Inc. (USA)				
HELLIGE (USA)	3–12	5	0.05–100	$12000
CardioMem CM 3000 (Germany)	3	8	0.03–70	$4600
Scan Tech Medical, LLC (USA)	3	6	0.05–100	$4700

Table 1 proves that the commercial value of cardiographs manufactured by known companies is excessively large in comparison with the product suggested. This is due to the fact that the nanosensors developed for this device make possible to receive signals of a nanovolt level without filtering and cardiac cycle averaging.

The development of a new generation of nanosensors and computerized ECG – the apparatus of high resolution to be used in clinics and at home – is relevant for improving the diagnostics of cardiovascular diseases, including early heart diagnostics of adults, children, infants and the fetus.

To solve the problem, a numerical model of excitation propagation in the heart muscle is to be studied.

Excitation propagates through the heart tissue at a certain rate, different for different parts of the heart (Fig. 2).

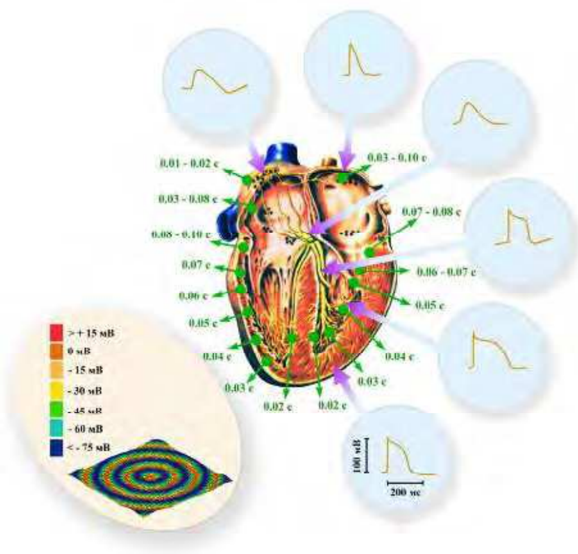

Fig. 2. Space-time scheme of a regular cardiac work of a human being.

Green lettering and arrows indicate the time of the excitation wave arrival at this region of the heart. Blue insets show the shape of the traveling-wave profile (the so-called "action potential") in different regions of the heart due to difference in properties of the excitable medium formed by the heart tissue. The beige inset demonstrates regular propagation of the traveling-wave excitation from the pacemaker area in the center (sinus node) towards the edges (along the working myocardium) in the simplest mathematical simulation model [3].

This results in a space-time scheme of heart excitation which ensures its functioning. In modeling excitation propagation, all the features of heart excitation are to be considered.

To simulate excitation propagation, one of the simplest models of the excitable medium, a two-component Aliev-Panfilov model is suggested in [4]. The model is implemented in the form of "reaction-diffusion" equations.

$$\frac{\partial u}{\partial t} = -ku \cdot (u-a) \cdot (u-1) - uv + \Delta u, \qquad (1)$$

$$\frac{\partial v}{\partial t} = -\left(\varepsilon_0 + \frac{\mu_1 v}{u + \mu_2}\right) \cdot (v + ku \cdot (u - a - 1)), \qquad (2)$$

where u(x, y, t) is a dimensionless function corresponding to the transmembrane potential, and u(x, y, t) is a dimensionless function corresponding to a slow membrane recovery current. The bonds between the heart muscle cells are defined by diffusion terms of the equations, and the dynamics of a single cell is defined by nonlinear terms of the equations. After a series of experiments, for better concordance of the system to the properties of the heart muscle the model parameters were determined: $k = 8.0, \varepsilon_0 = 0.01, \mu_1 = 0.2, \mu_2 = 0.3, a = 0.15$.

To implement the simulation of the excitation propagation in the heart within the concept of the cardiovascular system (CVS) assessment a hardware-software complex is going to be developed in Laboratory No 63, Institute of Non-Destructive Testing. The algorithm of its functioning is shown in Fig. 3.

According to the algorithm, at first, the initial and boundary conditions of the model are assigned basing on the cardiographic information analysis. After that, the model parameters are determined for various compartments of the heart, and the excitation propagation is simulated. The simulation results are used to visualize excitation propagation on the heart surface.

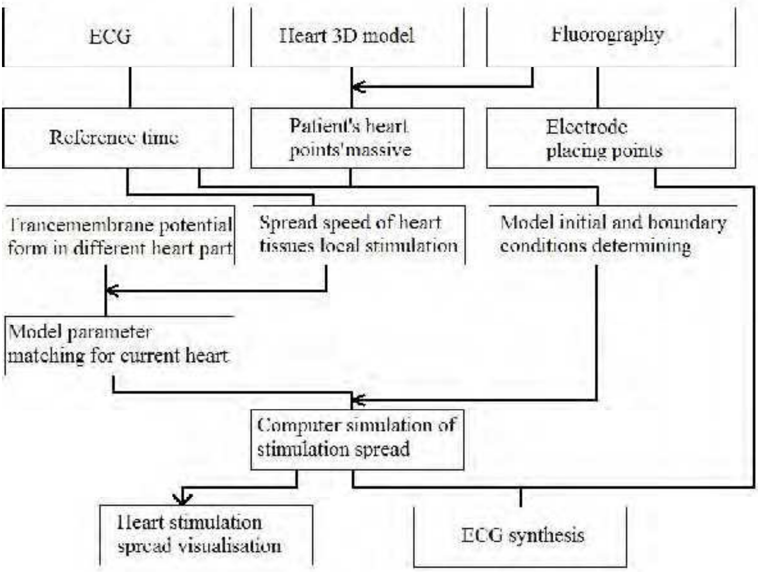

Fig. 3. The algorithm for simulation of excitation propagation in the heart

The model of the cardiac electrical activity makes possible to determine the "electrical portrait" of the patient's heart within the cardiac cycle, which enables to identify the diagnostic features in the analysis of indirect parameters determined by simulating the electrical processes in the heart and ECG output data from nanosensors.

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