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Magnetic resonance cardiorhythmography as a method of study of human's cardiovascular system condition

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Abstract

In this article a highly sensitive method for graphic recording of cardiogram by detecting the signal of nuclear magnetic resonance (NMR) of human finger has been developed and signals directly related to movement of blood ejected by the heart into the vessels have been studied. Changes in the behavior of signals depending on the condition of the cardiovascular system of person have been discovered.

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Keywords: Nuclear magnetic resonance (NMR), proton, heart, blood flow, pulse, pulse wave, cardiogram.

1. Main text

Various options of methods, one way or another connected with analysis of heart rate and pulse waive are widely used in modern medicine. There are several ways of registration of heart beat, including well known hardware techniques: using heart rate monitor, pulse oximeters, sphygmographs, electrocardiograph (digital ECG) and others.

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The most common and developed method is ECG – a technique of detection and investigation of electric fields generated during operation of heart muscle.

However, a number of factors seriously limit the ability of the standard ECG, for example, because of the small amplitude the P wave is not always clearly identified, the presence and absence of which are often decisive for correct diagnosis of arrhythmias. When all the values of ECG method, its assessment should be carried out only on the basis of clinical data, because various pathological processes may lead to the similar changes in the ECG. The contractile function of heart can be judged only indirectly using the ECG method. Furthermore, it should be noted that the decoding of ECG requires special knowledge and, for example in home environment this is not always possible to implement. What about method of graphical registration of pulse fluctuations of arteries wall (sphygmography), it is known that the shape and amplitude of pulse fluctuations are changes if there is peripheral arteries lesion or another illness, so, it can be independent of heart work.

In this regard, it is important to develop methods that complement the existing ones, and enable to receive new information about work of heart not through walls of vessels or electrical fields, but directly from blood flowing in vessels.

The use of NMR for this purpose allows to register signal directly from protons of blood, that in turn may allow considering not only the state of the cardiovascular system, but also the dynamics of change of proton concentration in blood due to external (medication) and internal (increased glucose) factors.

In this article [Protasov (2010)], using the developed NMR-relaxometer with a continuous generation of high-frequency (HF) energy, and the rapid entry into resonance and subsequent staying there for the decay time of the signal, there have been NMR signals recorded from fingers of the human hand, due to the work of heart muscle. In this connection, measuring the NMR signal from the protons of blood flowing through vessels we can directly receive accurate information about the nature of blood supply vessels. However, the large noise and presence of water, contained in the stationery tissue, make impossible to obtain the quality of the signal, which would be sufficient for a detailed study.

2. Experimental procedure

Figure 1 shows a block diagram of an apparatus for recording a pulse signal from a finger of the human hand.

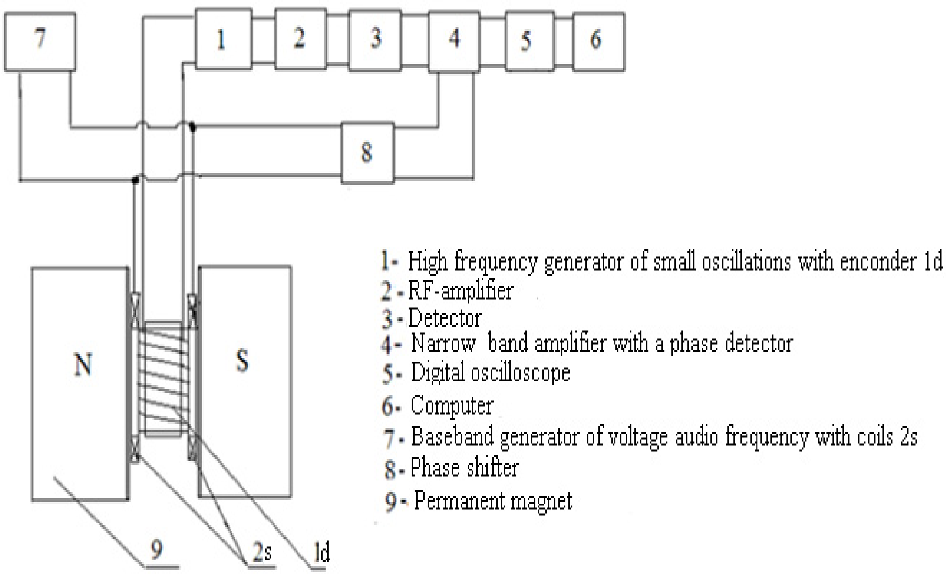

Fig. 1. Block – diagram.

The device operates as follows. High frequency generator of small oscillations with encoder (2), is an amplifier with a positive feedback, which supports continuous generation. The RF current from the generator flows through the coil sensor 1d, which is in a constant magnetic field and where the patient's finger is [Bondarchuk (2010)]. Upon the occurrence of resonance, finger absorbs radio frequency energy, causing a reduction in oscillation amplitude whenever the magnetic field (or frequency) due to modulation passes through the resonant value. Further, voltage on the oscillation circuit modulated by the NMR signals is amplified with RF (2) and detected by detector (3), and then enters the narrow-band amplifier with a phase detector (4) and further, to one of the five channels of digital oscilloscope (5) that is capable of simple mathematical operations, where is recorded into the file and then computer (6) takes its processing. By the generator of voltage audio frequency with coils 2s (7) magnetic field is modulated at a frequency of Ωm = 1067 Hz. The signal from the generator fed to the two single-layer coils 2s, executed in Helmholtz configuration, and also to the tuned amplifier 4 with the phase detector.

Note that the NMR sensor and parameters, as well as, design and dimensions of the magnetic system (9) are the same as in (3). Homogeneity of the magnetic field in these experiments was $\Delta H / H = 7 \cdot 10^{-5}$. The constant magnetic field was H = 3770 Oe.

3. Measurements results

Figure 2a shows pulse oscillogram obtained using a conventional heart rate monitor and figure 2b NMR – cardiogram of a patient in the older age group. Comparison of figures 2a and 2b shows that pulse curve, obtained by NMR (Fig.2b) provide for finer pulse details enabling diagnosis of diseases of cardiovascular system of human, while as for Figure 2a, only the amplitude of heart rate can be estimated. Observed on oscillogram Fig.2b "dicrotic teeth" may be associated with the spread of the pulse wave. Moreover, fig. 2b represents that the patient has "pulse deficit" because not every heart [Chazov (1998)] (there is no "tooth" on the maximum signal on the left) beat gives rise to a pulse waive. From the presented oscillogram it is easy to determine heart rate. In addition we can also estimate the time of stuffing the blood into the aorta, t_b and fall time t_c.

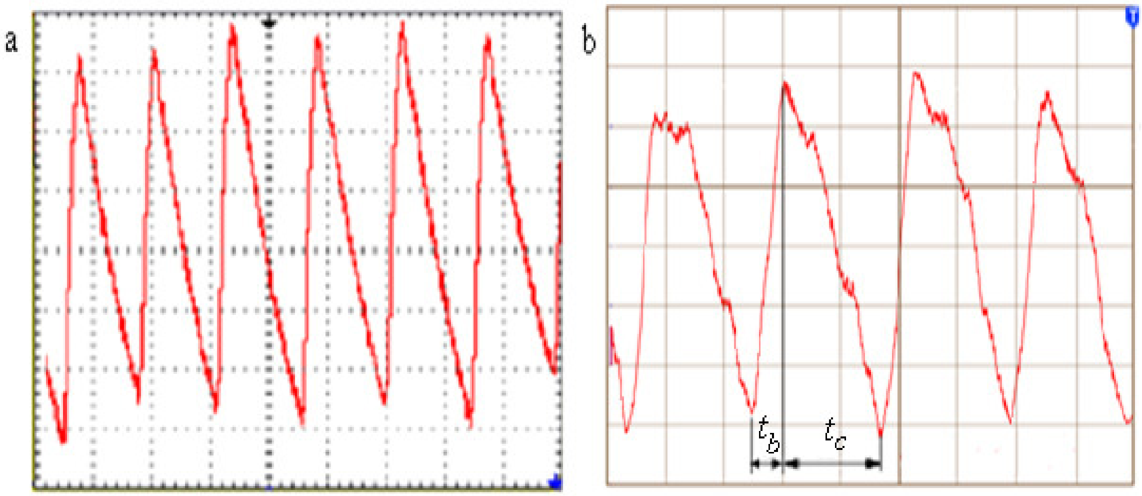

Fig. 2. (a) Oscillogram pulse obtained using a conventional heart rate monitor (Scan-axis "x" - 1 sec / div; axis "y" - 1 V / div); (b) NMR – cardiogram (Scan-axis "x" – 0.5 sec/div, along the axis "y" – 0.2 V/div).

Figure 3 shows cardiogram patient younger age group after exercise. On the Fig.3 it can be seen that the reflected wave reaches the heart at the end of the heart beat or early relaxation phase that allows the heart to work easier and helps to improve blood flow in the vessels, as their blood supply occurs predominantly during diastole.

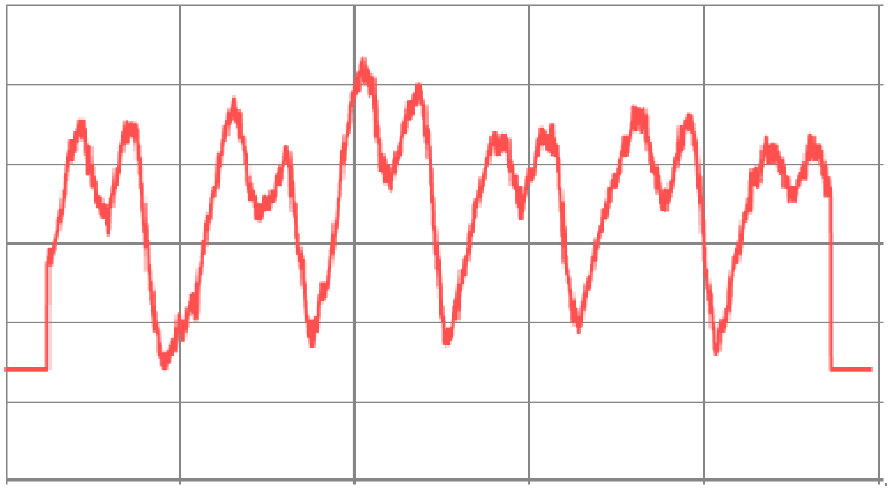

Fig.3. NMR – cardiogram of a patient in the youngest age group after exercise (Scan-axis “x” – 1 sec/div, along the axis “y” – 1 V/div).

In this case, two peaks are clearly shown, the first peak corresponds to the direct wave, while the second, smaller one to the maximum of the reflected wave. This kind of pulse wave is normally observed in healthy people without heart diseases. The difference in the amplitude of "teeth" (Fig. 2b and 3), apparently due to the fact that the patients belong to different age groups. It is believed that the frequency and duration of the pulse wave is dependent on the characteristics of the heart beat and the size and form of its peak – the condition of the vascular wall.

Figure 4a shows the NMR cardiogram of the patient with a diagnosis of “atrial fibrillation of heart”. Of the waveform it can be seen that the amplitude of stuffing and downs of blood in the vessels of human finger varies, and the violations of heart rate (from 50 beats per minute to 80 beats per minute), rhythm and sequence of excitation and contraction of the heart occur. Throughout all cardiogram there observed small "teeths", which appears because reasons still unknown. Fig.4b shows the cardiogram of the same patient after an operation "electrical cardioversion 200 J", which allows to recovery sinusoidal beat.

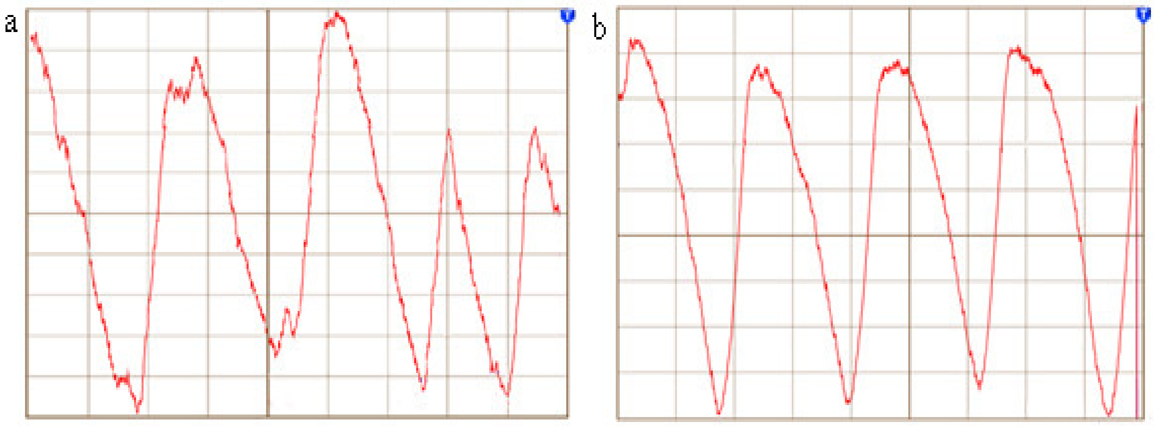

Fig.4. (a) NMR (Scan-axis “x” – 0.5 sec/div, along the axis “y” – 0.2 V/div); (b) NMR cardiogram of the same patient after an operation "electrical cardioversion 200 J" (Scan-axis “x” – 0.5 sec/div, along the axis “y” – 0.2 V/div).

Also on Fig.4b the lack of dicrotic notch is noticeable, and we still don't know how to explain this, but we can notice, that it indicates the possible presence of atherosclerosis, hypertension and these types of pulse waves are characteristic for the elderly patients.

4. Conclusion

Method of non-invasive registration of human cardio-vascular system work using magnetic resonance proton cardiorhythmography has been developed and experimentally tested. This sufficiently easy method have no contra-indication to application and it enables possibility of high sensitive measurement of different anomalies of heart work and control of efficient unrhythmical and other medicine.

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