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NOISE METHOD FOR ASSESSING THE PARAMETERS OF CARDIAC ACTIVITY

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Abstract**—***Modern trends in medical practice put a number of requirements for measurement of cardiac activity, the main of which – to avoid possible complications from the procedure of investigation and the possibility of continuous measurement. The authors propose a noise method of measuring the cardiac output parameter, which provides not only the noninvasiveness of the measurement procedure and the possibility of continuous monitoring, but also avoids the transmission of current through human organs.*

Index Terms—Noise signal; active resistance; impedance cardiography; cardiac output; noninvasive method.

I. INTRODUCTION

Carrying out surgical interventions in a human body requires constant monitoring of the patient's cardiac activity. One of the main indicators of cardiac activity is the parameters of central hemodynamics, in particular, the value of the parameter of cardiac output or minute volume of circulation.

Initially, this parameter was measured invasively by the thermodilution method, which needed to introduce a special Swan-Gantz catheter through the jugular vein through the right heart sections into the pulmonary artery. A bolus of a certain volume and temperature is then introduced into the catheter through the canal, and the change in blood temperature after the bolus is entered is measured. Based on the obtained values, the dilution curve is constructed, and on the basis of it the value of cardiac output is calculated, the method requires averaging of at least three measurements [1].

This method is still considered to be an exemplary method because it provides the highest accuracy of estimation of the cardiac output parameter [2]. The main drawbacks that significantly limit its use are the high likelihood of injury, the dependence of the measurement result on the skills of the operator and the impossibility of continuos measurement.

II. PROBLEM STATEMENT

Considering the disadvantages of the thermodilution method, much attention is being paid today to the development of non-invasive methods of estimating the cardiac output parameter, in particular, the impedance cardiography method, the method based on the determination of the pulse wave transit time and the ultrasonic method. Their common feature is the use of an probing electric or electromagnetic signal that interacts with the human body. For example, when using the method of impedance cardiography with the help of contact electrodes, a high-frequency electrical current is passed through electrodes on the chest, and other pairs of electrodes at other points of the chest measure the generated voltage. According to the data obtained, they plot a change in impedance during one contraction of the heart. In some cases, even a small current passing through human tissue is dangerous, besides the current flow on the verge of electrode-skin interaction leads to electrochemical interaction of surface layers of moisture with electrodes. The phenomenon of electrolysis adversely affects the condition of the skin and reduces the accuracy of the measurement result.

III. STRUCTURE AND ALGORITHM OF NOISE MEASUREMENT TOOL FOR CARDIAC OUTPUT PARAMETER

In such circumstances, it is advisable to use methods that allow you to measure the active resistance of the object under study without applying an external electric voltage to it or passing through it. This possibility exists in principle if you use your own electrical noise of the control object as an informative parameter.

An example of the application of such a method is proposed in [3]. In the proposed device, the noise voltage obtained from the object under study is

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measured after amplification in the field of high frequencies, quadratic detection and averaging. The measurement result, according to the author, is proportional to the active component of the full resistance of the object under study. However, it should be noted that the level of informative noise of the investigated object is commensurate with the level of high-frequency component of the intrinsic noise of the amplifier and the quadratic detector. This results in a significant distortion of the measurement result.

The authors propose a new structure and algorithm for the operation of the noise measurement tool for a cardiac output parameter, which minimizes the influence of the inherent noise of the elements of the conversion tract on the measurement result. The functional diagram of the proposed device is shown in Fig. 1.

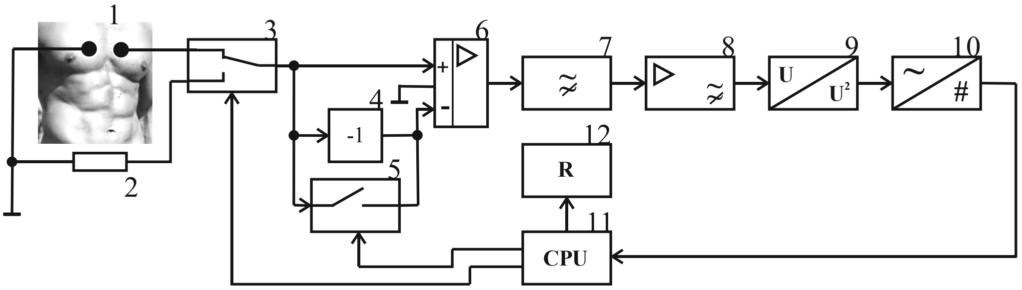

Fig. 1. Functional diagram of the noise measurement tool for cardiac output parameter: 1 is the investigation object with unknown resistance; 2 is the reference resistor; 3 is the controlled switch; 4 is the analog inverter; 5 is the controlled key; 6 is the differential amplifier; 7 is the high pass filter; 8 is the high frequency amplifier; 9 is the quadratic detector; 10 is the analog-digital converter; 11 is the microprocessor; 12 is the recording device

The principle of operation of the diagram is as follows. When the controlled switch 3 has switch position like in the diagram, from the test object with unknown resistance R_x a noise voltage is obtained $Ux(t)$. Voltage $Ux(t)$ at the output of the switch 3 is divided into two equal noise voltages $U_1(t)=U_2(t)=Ux(t)$. Voltage $U_1(t)$ is fed to the direct input of the differential amplifier 6, and voltage $U_2(t)$ after inversion, it is fed to the inverse input of the same amplifier. The output of the differential amplifier thus produces an amplified signal of the sum of two identical voltages $U_1(t)$ i $U_2(t)$. It should be noted that noise voltage $Ux(t)$, which is obtain from the test object with resistance R_x commensurate with the inherent noise of the differential amplifier 6.

If the noise voltage $Ux(t)$ to present in complex form as, the output voltage $\dot{U}x$, output voltage of differential amplifier 6 with the open key 5 will be the sum of the complex noise voltages:

$$\dot{U}_3=2k_1\dot{U}x+\dot{U}_L+\dot{U}_H, \qquad (1)$$

where k_1 is the gain of differential amplifier 6; $\dot{U}_L$ is the complex voltage of low frequency component of noise; $\dot{U}_H$ is the complex voltage of high frequency component of noise.

From amplified total information noise signal and corresponding differential amplifier noise after filtering in the high pass filter 7 only the high frequency component of the total noise signal is allocated. Next it is further amplified by a high-frequency amplifier 8 and is converted to a quadratic detector 9. The rectified signal of the high frequency component of the noise voltage is supplied to the integrating analog-digital converter 10, where it is averaged over a given time interval *t*. From the averaged voltage a constant component of the voltage is obtained:

$$\dot{U}_4=S\left[\overline{k_2k_3\left(2k_1\dot{U}x+\dot{U}_H+\dot{U}_F\right)}\right]^2, \qquad (2)$$

where k_2 is the transmission coefficient of the bandpass filter 7; k_3 is a gain of the high frequency amplifier 8; S is a steepness of conversion of the quadratic detector 9; $\dot{U}_F$ is the integrated noise filter of the bandpass filter 7 taking into account the noise of the high frequency amplifier 8.

Constant component of the voltage in the form of a digital code N_1 is read from the output of the integrating analog-digital converter 10 and is stored in the memory of the microprocessor 11. In determining the code N_1 it is necessary to consider that thermal noise of resistance R_x the test object and the intrinsic noise of the measurement circuit elements are not correlated. Therefore, their average output is zero:

$$\overline{\dot{U}_x\dot{U}_F}=0; \qquad \overline{\dot{U}_x\dot{U}_H}=0; \qquad \overline{\dot{U}_H\dot{U}_F}=0. \qquad (3)$$

Given the condition (3) the digital code looks like:

$$N_1 = \frac{k_2^2 k_3^2 S\left(4k_1^2 \overline{U}_x^2 + \overline{U}_H^2 + \overline{U}_F^2\right)}{q} + \Delta N_1, \tag{4}$$

where $\overline{U}_x^2$ is the mean square noise voltage (variance) of the object with an unknown resistance R_x; $\overline{U}_H^2$ and $\overline{U}_F^2$ is the variance of the intrinsic noise of the measurement circuit elements; q is the unit of the low-order analog-to-digital conversion; ΔN_1 is the random errors analog-to-digital conversion in the first step of measuring cycle.

In the next cycle of the measuring cycle on the microprocessor 11 signal, switch 3 is moved to the lower position. In this case, the input of the differential amplifier 6 the total noise voltage arrives $2U_0$ from the reference resistor 2. In the output of the amplifier 6 is produced a total noise voltage, similar to the expression (1):

$$\dot{U}_5 = 2k_1\dot{U}_0 + \dot{U}_L + \dot{U}_H. \tag{5}$$

As a result of analog-to-digital conversion of voltage into microprocessor 11 a digital code similar to an expression is memorized (4):

$$N_2 = \frac{k_2^2 k_3^2 S\left(4k_1^2 \overline{U}_0^2 + \overline{U}_H^2 + \overline{U}_F^2\right)}{q} + \Delta N_2, \tag{6}$$

where ΔN_2 is the random errors of analog-to-digital conversion in the second cycle of the measurement cycle.

In the next cycle of the measuring cycle on the microprocessor 11 signal, key 5 is closed, causing the inverter to bypass 4. On the direct and inverse inputs of the differential amplifier 6 two identical noise voltages arrive. Output signal of differential amplifier 6 in this case it is determined only by its own noises:

$$\dot{U}_6 = +\dot{U}_L + \dot{U}_H. \tag{7}$$

As a result of analog-to-digital conversion, the voltage of the noise of the differential amplifier 6 with the same elements of the measurement circuit forms a third digital code:

$$N_3 = \frac{k_2^2 k_3^2 S\left(\overline{U}_H^2 + \overline{U}_F^2\right)}{q} + \Delta N_3, \tag{8}$$

where ΔN_2 is the random errors of analog-to-digital conversion in the third cycle of the measurement cycle. Digital code N_3 is also remembered in the memory of the microprocessor11.

By code values N_1, N_2 and N_3 the ratio of difference codes is calculated:

$$Q = \frac{\overline{N_1} - \overline{N_3}}{\overline{N_2} - \overline{N_3}}. \tag{9}$$

Substituting into an equation (9) the value of the digital codes (4), (6) and (8), obtain:

$$Q = \frac{\overline{U_x^2}}{\overline{U_0^2}}. \tag{10}$$

Dispersion thermal noise resistance of the investigated object 1 is determined Nyquist formula [4]:

$$\overline{U_x^2} = 4kT_1\Delta f \operatorname{Re} Z, \tag{11}$$

where k is the Boltzmann's constant; T_1 is the thermodynamic temperature of the test object 1; Δf is the band of thermal fluctuations emitted by the high pass filter 7 of measuring diagram; $\operatorname{Re} Z = R_x$ is the active component of full resistance Z test object 1.

The variance of thermal noise of the sample resistor 2 is determined by its ohmic resistance R_0:

$$\overline{U_0^2} = 4kT_2\Delta f R_0, \tag{12}$$

where T_2 is the thermodynamic temperature of the reference resistor 2.

After substituting the values of the variances (11) and (12) into (10), obtain:

$$Q = \frac{T_1 \operatorname{Re} Z}{T_1 R_0}. \tag{13}$$

Provided the sample resistor 2 is placed in thermal contact with the test object 1 ($T_1 = T_2$), equation (13) looks like:

$$Q = R_x / R_0. \tag{14}$$

From relation (14) we get the current value of the active resistance of the test object 1:

$$R_x = Q R_0. \tag{15}$$

Microprocessor 11 by the formula (15) calculates and displays the current value of the active resistance of the test object on the recording device 12.

After the calculations on the signal microprocessor, key 5 opens and new measuring cycle is started and as result new values of codes N_1, N_2 and N_3 are determined.

From the equation (10) and (15) shows that the end result after the measurement processing computer codes interim measurements (N_1, N_2 and N_3) does not depend on the level of intrinsic noise of the measurement circuit elements (U_L, U_H and U_F), as well as the instability of the conversion factors of the measuring path (k_1, k_2, k_3 and *S*). This ensures high accuracy in measuring the active resistance values of the test object 1.

IV. RESEARCH RESULTS

The study substantiated the possibility of using the noise method of estimating the cardiac output parameter. Proposed a functional diagram and algorithm of the device, which uses a noise signal can calculate the value of cardiac output parameter.

Usage proposed 12-bit analog-digital converter, for example, brand ADC122S051 manufactured by National Semiconductor with conversion time 2 mks provides for a minimum of 100 measurement cycles per heartbeat, taking into account the need to average the measured signals, switch them, perform computational operations and exchange data. If necessary, increase the number of measurement data is possible using analog-to-digital converters with greater performance, such ADC101S101.

V. CONCLUSIONS

The proposed method of noise measurement parameter cardiac output will reduce the influence of measuring tool to the patient, even compared with known noninvasive methods. Also, method helps improve the measurement accuracy by eliminating factors of influence transient processes during the electrode-skin current transit on point.

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К. Л. Шевченко, С. А. Левицький, Ю. В. Штефура. Шумовий метод оцінки параметрів серцевої діяльності

Розглянуто сучасні тенденції та вимоги до вимірювання параметрів серцевої діяльності. Головні з них – уникнення можливих ускладнень від процедури вимірювання та можливість неінвазівних вимірювань. Запропоновано шумовий метод вимірювання параметру серцевого викиду, який забезпечує не тільки неінвазивність процедури вимірювання та можливість постійного моніторингу, але й уникає зовнішніх електричних впливів на організм людини.

Ключові слова: шумовий сигнал; активний опір; імпедансна кардіографія; серцевий викид; неінвазивний метод.

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К. Л. Шевченко, С. А. Левицкий, Ю. В. Штефура. Шумовой метод оценки параметров сердечной деятельности

Рассмотрены современные тенденции и требования к измерению параметров сердечной деятельности. Главные из них – исключение возможных осложнений от процедуры измерения и возможность неинвазивных измерений. Предложен шумовой метод измерения параметра сердечного выброса, который обеспечивает не только неинвазивность процедуры измерения и возможность постоянного мониторинга, но и не требует внешних электрических воздействий на организм человека.

Ключевые слова: шумовой сигнал; активное сопротивление; импедансная кардиография; сердечный выброс; неинвазивный метод.

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