Measurement of electrical resistance in selected points of the human skin by low currents

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Abstract

Presented device for the measurement of electrical resistance in selected points of the human skin using extremely small currents. A model of the device measuring circuits was created. A set of precision resistors was used for optimization model parameters. The results of experiments on human skin was described.

Introduction

The described device for measuring the bioelectrical impedance of the human skin is one of the possible means of monitoring the progress of treatment for damaged spinal injury somatic and autonomic functions of the victim. It is assumed that the processes of change in anatomical and physiological state of the human limb in the states of pathology and recovery should be reflected in the measured characteristics of the skin in certain areas of his body.

Diagnostic value of measuring skin conductivity due to the presence of subcutaneous galvanic currents tied-up with biopotentials electrical activity of muscles and blood vessels near the electrode probe. In other words, the difference between the observed electrical activity by means of myography sluggish and active muscles should be reflected in the value of subcutaneous galvanic current. According to reports, what occur under the skin, the so-called "physiological electrical" currents have a value of up to 6 μA.

The skin is a rather complex and multi-layered organization. The top layer (epidermis with a horny layer) has the greatest resistance (hundreds of megohms). Beneath it is the "dermis", filled with blood vessels, sweats and lymph. This layer has a low resistance. A lower flow weak galvanic currents. By varying the magnitude of currents applied to the human skin range of up to 10 μA and, measuring the received voltage in the skin, we can determine not only the resistance of the human skin, but the "normal current" person.

In assessing the biological potentials measured:

1. The electric potential of the skin. In healthy people, the biologically active points (BAP) he is 2 .. 3 mV higher than the values at neighboring points of the skin [1]. Depending on the severity of the disease, the electric potential of the skin can be both above and below this value. Measurement of electrical potentials of the skin is also used myography and electroencephalography.

2.The bioelectrical impedance between two points of the body. For example, the Fall-Verenera device, to find and work with BAP, measures resistance (90 kOhm and above) between the palm of the hand and the skin area Zakhar'eva-Ged [2] - 9 V with flowing currents from 0 to 100 mA.

In this regard, the KIAM developed device were brought against more stringent requirements than the equipment used in the practice of electro-diagnostic [1]. It was assumed that the sensor must provide a low impact on the person at time of measurement, to have a high sensitivity and be resistant to interference.

1 Simulation of the measurement channel. The formulas for calculating the electrical parameters of the patient's skin

Model circuit currents measured at the site of the skin resistance is described by the equivalent circuit shown in (Fig. 1). In this model, the current i_1 is given by its selected value, and the measured voltage drop between the points of skin contact K_1 and K_2. The resulting value is a function of the desired skin resistance R_x and proceeding thereon unknown current i_2 (through the skin) and the unknown potential U (physiological potential). In this case, the resistance R^* is the load resistance device with a constant value.

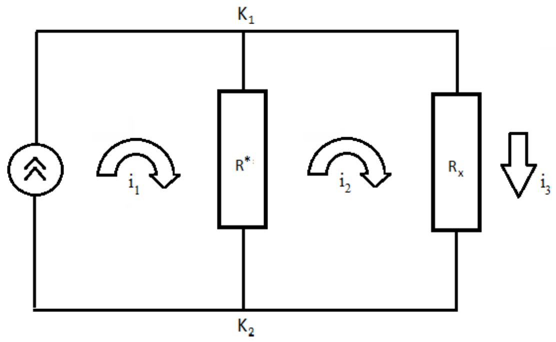

Figure 1: The equivalent scheme for the calculation of resistances and currents

It was observed that for different signs given by the current equivalent resistance (R_x) have different values. Besides the value of bitwise current DAC were not proportional to powers of 2. The result was 17 parameters that require further definition:
- The resistance of R^*,
- Conversion factor values given by the current,
- The value of the ADC, corresponding to the zero voltage,
- Current actual code defined by 1 bit of the DAC,
- Real leakage current by 1 bit of the DAC,
- Current actual code defined by 2 bit of the DAC,
- Real leakage current by 2 bit of the DAC,
- Current actual code defined by 3 bit of the DAC,
- Real leakage current by 3 bit of the DAC,
- Current actual code defined by 4 bit of the DAC,
- Real leakage current by 4 bit of the DAC,
- Current actual code defined by 5 bit of the DAC,
- Real leakage current by 5 bit of the DAC,
- Current actual code defined by 6 bit of the DAC,
- Real leakage current by 6 bit of the DAC,

- Current actual code defined by 7 bit of the DAC,
- Real leakage current by 7 bit of the DAC.

These 17 parameters separately determined for positive currents and negative currents. At the end - 34 parameter. In addition, it can be noted that although the DAC has 12 bits, but in reality, the above code 127 in the device is not in use. Bits through 8-12 do not used. Set of experiments on three high-precision active resistors value 1 MOhm, 100 kOhm and 30.1 kOhm at various codes of the DAC. At first optimization problem was solved in an abbreviated form - without leakage currents. This reduced the number of variables to 20. The function $F = \min(\sum_i (errADC_i)^2)$ was minimized, where $errADC_i$ - the difference of the measured ADC and received by the formula $ADC_i = DAC_i * k * \frac{R^* * R_x}{R^* + R_x} + ADC_0$.

The calculated values вЂ<вЂ<are shown in (Tab. 30).

Table 30: Table reduced set of values вЂ<вЂ<of the coefficients

Parameter	Negative currents	Positive currents
R*	2904.0559	2945.8007
koef	0.0870	0.0870
ADC0	2530.2827	2529.9661
k2	2.0817	2.0238
k4	4.1303	4.0471
k8	8.3197	8.1533
k16	16.6178	16.1117
k32	33.1855	32.2973
k64	66.3876	65.1572
k128	133.7718	129.7529

The errors for the negative currents are presented in Fig. 2. The errors for the positive currents are presented in Fig. 3.

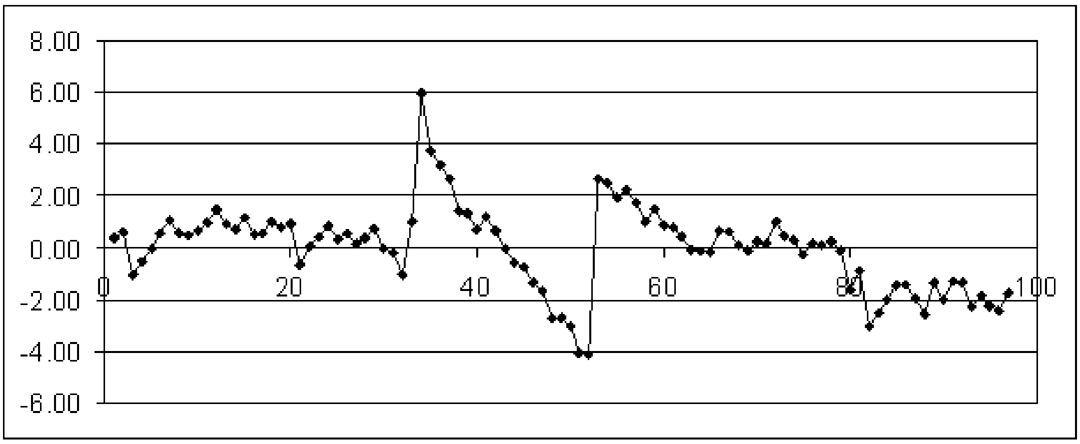

Figure 2: ADC Error with negative currents. X-axis - codes currents DAC, the Y - axis error in units of the ADC

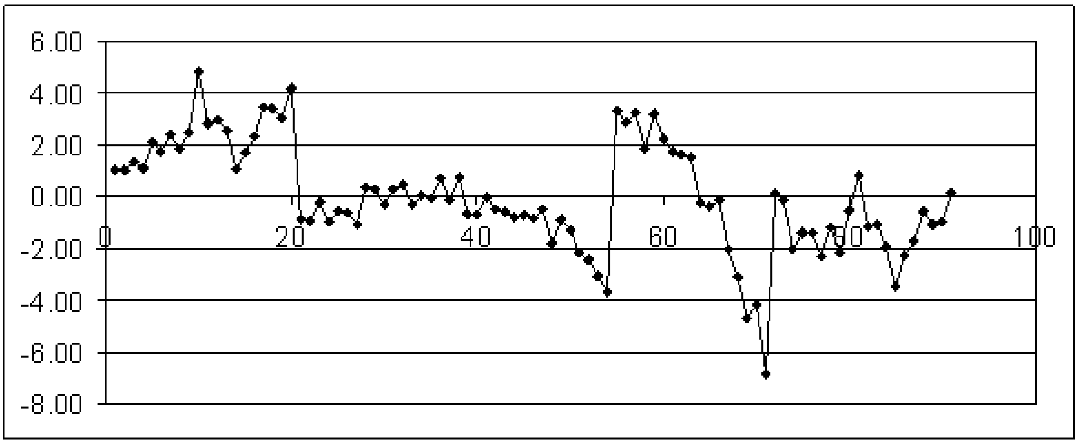

Figure 3: ADC Error with positive currents. X-axis - codes currents DAC, the Y - axis error in units of the ADC

Knowing coefficients (Tab. 30), it can measure the precision of resistance. The results are presented in (Tab. 31). Shows good coincidence of the results. The error occurs because of inaccuracies job precision resistances, which is used in the problem of minimization.

Table 31: Table of measurement precision resistors

The nominal values of resistance (kOhm)	The calculated values of resistance (kOhm)
1000.0	999.497
100.0	98.409
30.1	29.700

In carrying out experiments on the skin it is necessary to define two parameters - the total resistance of the skin R_x and physiological current i_3. There are two measurements at different values of the specified current i_1. According to the laws of Kirchhoff for electrical circuits there are equations:

$$\begin{cases} \frac{U_{K_2K_1}}{R^*} = i_1 - i_2 \\ \frac{U_{K_2K_1}}{R_x} = i_2 - i_3 \end{cases} \qquad \begin{cases} i_2 = i_1 - \frac{U_{K_2K_1}}{R^*} \\ i_3 = i_2 - \frac{U_{K_2K_1}}{R_x} \end{cases}$$

Excluding the variablei_2, get $i_3 = i_1 - U_{K_2K_1} \circ \left(\frac{1}{R^*} + \frac{1}{R_x}\right)$. Make two measurements at different currents $i_1^{(1)}$ and $i_1^{(2)}$. It correspond to two voltage measurements $U_{K_2K_1}^{(1)}$ and $U_{K_2K_1}^{(2)}$. We obtain the system of equations:

$$\begin{cases} i_3^{(1)} = i_1^{(1)} - U_{K_2K_1}^{(1)} \circ \left(\frac{1}{R^*} + \frac{1}{R_x}\right) \\ i_3^{(2)} = i_1^{(2)} - U_{K_2K_1}^{(2)} \circ \left(\frac{1}{R^*} + \frac{1}{R_x}\right) \end{cases}$$

If we assume that the currenti_3 does not change when you change the impact of the currenti_1, that is $i_3^{(1)} = i_3^{(2)} = i_3$, we can find the resistance R_x, subtracting the second equation from the first.

$$\frac{1}{R_x} = \frac{i_1^{(1)} - i_1^{(2)}}{U_{K_2K_1}^{(1)} - U_{K_2K_1}^{(2)}} - \frac{1}{R^*}$$

Substituting this expression in the first equation, we get

$$i_3 = i_1^{(1)} - U_{K_2K_1}^{(1)} \circ \frac{i_1^{(1)} - i_1^{(2)}}{U_{K_2K_1}^{(1)} - U_{K_2K_1}^{(2)}}$$

the expression for physiological current.

2 Realization of measuring tract

The main requirements [3, 4] underpinning the scheme of the device, were:
- Measurements should be given stabilized currents,
- Range of working currents must lie in the range from 0.1 to 250 μA,
- Resistance is determined by the voltage drop between the electrodes,
- The direction of the current between the electrodes must be managed.

On the basis of these requirements and taking into account available of the element base, a measuring device developed with the following properties:
1. The connection of the device with the computer is carried out through USB bus.
2. Power supply of the device is a voltage of +5V directly from the USB bus. Current consumption I_{pow}= 30 mA.
3. Scheme of the device provides complete galvanic isolation for power supply of digital and analog portion of the device from the USB bus.
4. Supply voltage of the analog portion of the device is provided by a built-in DC-DC convertors, providing a working voltage of ±12V. (V_{s-}=-12V and V_{s+}=+12 V).
5. The supply voltage of the digital part (microcontroller) +3.30 V.
6. The range of software defined currents is regulated by a 12-bit D/A converters and provides adjustment in the range 0 for up to 250 μA with an accuracy of 60 nA.
7. Measuring range of input voltage is ±1.65 V.
8. The sampling frequency of the input of the ADC: f_{ADC}=1.3 kHz, depth of quantization - L_{ADC}=12 bits.

The main noise component, as it was revealed in the process of carrying out experiments on human skin, is an essential influence of an electric network of alternating current of 50 Hz in the human body. The human body plays the role of an antenna and transmit the resulting impact of the electrical network in the device. Fig. 4 shows photographs of noise at the output of the input of the operational amplifier, the shot of the oscilloscope.

3 Design of the device

On a horizontal Board implemented the digital part, and the vertical Board - analog portion of the device (Fig. 5).

In addition to the microprocessor, at the bottom of Board posted the following elements:

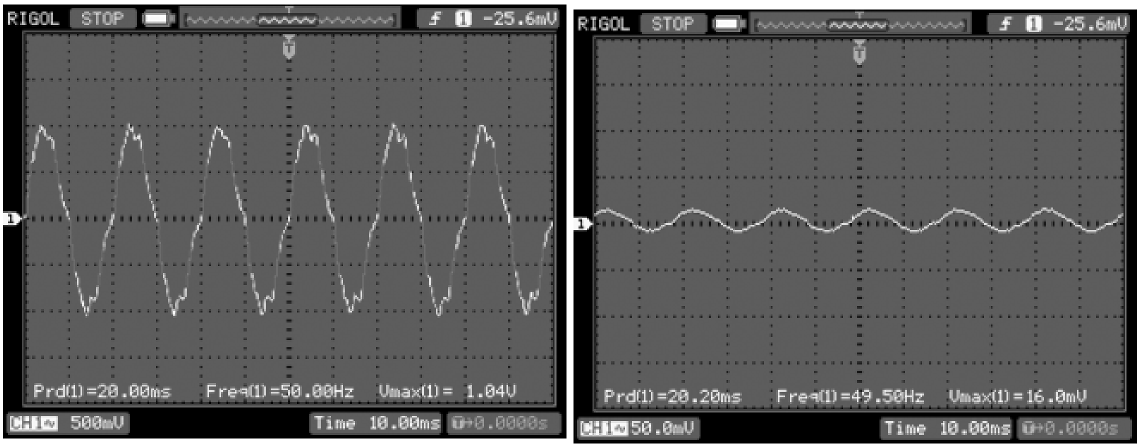

Figure 4: Noise coming into the instrument with the human skin - noise electric networks of an alternating current with frequency of 50 Hz. The left photograph - maximum recorded a hindrance without the hardware noise reduction. The right photograph - the regime of maximum hardware noise reduction. Oscilloscope probe is included with the divisor of 1:10

Figure 5: General view of the device

- Switching power supply (DC-DC converters) with output voltages of +5 V and ±12 V and galvanic isolation of input and output circuits.
- Power supply processor, built on a linear voltage regulator TPS76333, ensuring the power circuit with a voltage 3.3 V.
- Quartz oscillator with a frequency of 32 kHz.
- Chip USB interface.
- Optical isolation of signals.
- LED indicators and function buttons.

4 Description of the experiments

Experiment 1.

Consider the measurement of the supply current of a constant 0.2 μA on the palm of the hand of the human with the change of its direction with a frequency of 1 Hz. In Fig. 6 shows a plot of the polarity of the supply current, up - measured voltage, ensuring the permanence of the current set the polarity of the electrodes attached to the palm.

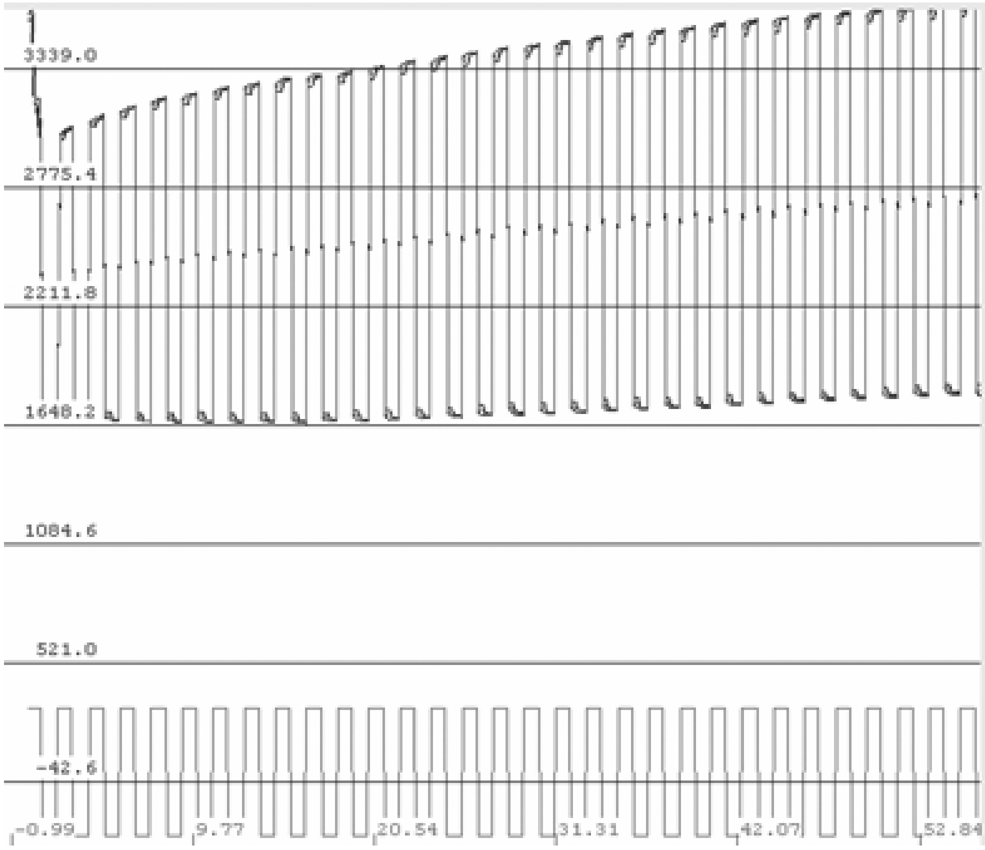

Figure 6: Measurement of voltage on the skin of the palm. X-axis - time in seconds, the Y-axis - voltage in mV

Attention should be paid to the observed volatility of the values of the measured voltage at one and the same current (Fig.6). For the modelling and assessment of parameters of these changes, you need to add to the model of parallel resistance R_x some capacity C_x, which value which should be determined by treating together a sequence of measurements of varying magnitude of voltage drop in the measuring points of the skin.

For given values of measurements of the received value of resistance R_x is the value of about 2 MOhm, and the value of the physiological current i_3, slowly decreasing of the value of 58 nA the value to -43 nA, as shown in Fig. 7.

In addition to the local voltage changes on the sites, connected with the permanent set currents with their duration in 1 sec, has a more prolonged global change of the voltage associated with the body's reaction to the weak current effects or independent of the changes taking place physiological currents in connection with the functioning of the organism. Finding out these circumstances requires additional experiments.

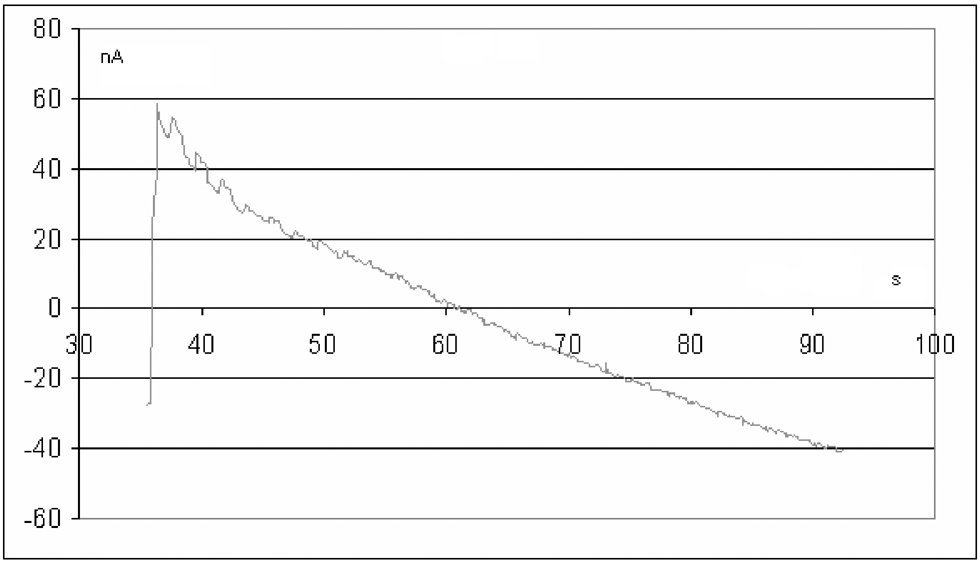

Figure 7: The physiological current at the experiment on the skin of the palm

Experiment 2.

The experiment was conducted on the left hand of the patient, electrode with gel. The first electrode attached to the measuring point of the pulse, and the second - on the inner side of the hand between the elbow and the wrist. The supply current 0.37 μA, with a frequency of 1 Hz changing direction.

At 230th seconds was massage left hand (the failure of the Fig. 8).

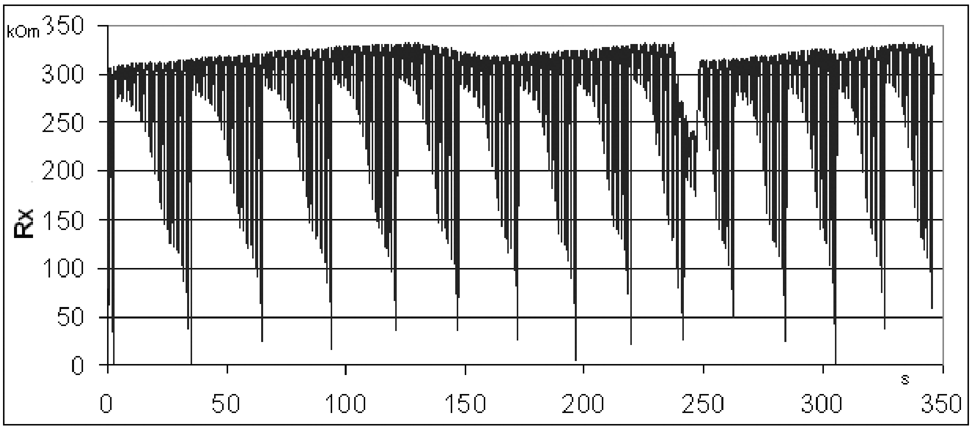

Figure 8: The electrical resistance of the skin on the inside of the hand between the elbow and the wrist

It is interesting the periodic (about 25 seconds) jumps of the measured resistance and vibration top of the chart.

Experiment 3.

The experiment was carried out on the right foot of the patient, electrode with gel. The first electrode attached below the inner ankle, and the second on the inner side of the foot in the middle of the tibial bone. The supply current 0.366 μA, with a frequency of 1 Hz changing direction.

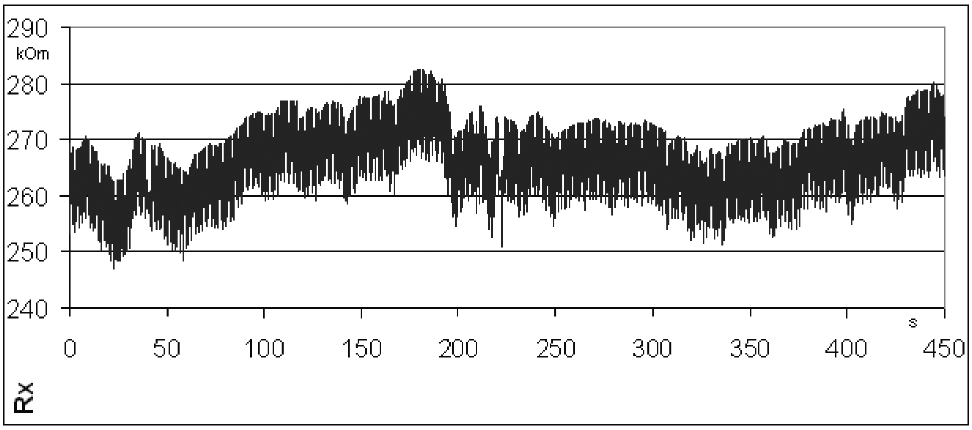

Figure 9: The electrical resistance of the skin on the inside of the foot in the middle of the tibial bone

From 180 seconds for about 60 seconds patient strained muscle in his leg (Fig. 9 sharp fall schedule down). The structure of the skin of the hand and foot are different as can be seen from figures.

Conclusion

The problem of developing a device to track the process of rehabilitation of the spinal patients already at the first stage of their treatment has been solved. One of the main objectives of the observations in this phase is to provide an objective diagnosis and recording changes in the patient during treatment For this purpose here is uses device of skin conductance patient's foot by tools similar devices matrix tactile stimulation of patient's foot, developed at the Institute of Mechanics, BAS (Sofia) [5]. Constructed by these means maps showing the skin and the visceral processes in the human foot, will help in the treatment of spinal patients.

To solve the described problem of the sensory ensuring process treatment here is required increased sensitivity measuring parameters of skin conductance. Development experience has shown that after reaching a certain level value of the measuring currents of the main difficulties in the way of a high-sensitive sensor appear to be associated with the noise influence of the electric parameters of the human body, located in the electromagnetic field of electrical wiring the usual facilities. It designed special complex of hardware-software means to reduce the influence of external electric fields on measurements of skin conductivity.

Developed device has sensitivity able to see and measure the magnitude and the dynamics of changes of the subcutaneous weak electric currents. This makes it a promising tool for the natural-scientific experiments for the construction of new diagnostic methods for the determination of numerical physiological condition of the man.

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