Temperature distribution in microwave chamber using the phantom limb

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Abstract. This paper presents results of temperature distribution in the phantom limb under the influence of microwave radiation. Authors had been developed automated installation based on linear positioner and temperature detector for measuring thermal field distribution in phantom of human hand. It was shown that under the influence of impulse microwave radiation having a power of 40W at the phantom during 6 minutes leads to equable warming along longitudinal axis of phantom.

1. Introduction

Today, the problem of frostbite on people's limbs is urgent [1–4]. About a third of the Earth’s land surface is in conditions when the average air temperature in winter does not rise above 0 °C. Therefore, the risk of hypothermia and frostbite of the extremities increases. Frostbite accounts for 10 to 15% of accidents, while deep frostbite requires long-term treatment and can last for 65 days with large amputations of the limbs, increasing the likelihood of patient disability. At the same time, there are not a few cases of cold injuries among residents of high mountain regions in the equatorial part of the land [5,6].

Effective recovery of damaged tissue temperature may contribute to microwave radiation, allowing to carry out the heating of the tissue throughout the depth. Over the years, various methods of treating deep frostbite have not given satisfactory results. This became the motive for researching the possibility of using the microwave field to improve the treatment of cold injury. In the course of research carried out at Tomsk State University on animals (rabbits), the possibility of heating frostbite in a medical microwave chamber at a frequency of 2.45 GHz was shown. To use this technique on frostbite of human limbs requires a more detailed research. To avoid overheating, the heterogeneity of the nature of electromagnetic and thermal fields [7] in the volume of the heated limb should be thoroughly investigated. Carrying out such experiments in humans is prohibited, which greatly complicates the process of researches. Therefore, it is important to create a phantom limb that is as similar as possible to the human in dielectric properties, and to research the temperature distribution inside the phantom when exposed to microwave radiation.

2. Development of automated temperature distribution along the phantom measuring device

In this paper has been developed automated positioner of temperature probe to investigate temperature distribution in the capacity of the phantom in various sizes and configurations. The flowchart of automated positioner is presented in Figure 1.
Arduino Nano microcontroller is used to control linear positioner of temperature probe (Figure 2) through the A3967SLBT controller of the stepping motor.

Limit switch is needed in establishing zero reference point. Thermocouple installed on the moving part of the positioner provides temperature determination using cold-junction-compensated K-thermocouple to-digital converter MAX6675. In the course of experiment described below LT-300 electronic thermometer made by the company «Termex» (Russia) was applied as a heat sensor.
Electronic thermometer permits immersing in testing volume at depth of 55 cm corresponding to path of moving part. Temperature sensors displacement was provided at 1 cm set intervals.

Operation algorithm of a positioner control program has 2 modes: automatic and manual. Automatic mode implies automatically sensor transference along the phantom. Each sequent moving take place if only temperature herein hold fix. Temperature recording realized automatically. In manual mode transference of the sensor happens by clicking on the corresponding buttons, the noteworthy feature here is the need to record temperature values in ECM in manual way.

Figure 3 presented physical form of experimental facility based on «SMVi-200» device and linear positioner of temperature probe [8] (Figure 3). This framework was constructed from duralumin profiles.

High-frequency emissions effects on biological tissues occurs mainly through heating by the warm produced resulting from radiation absorption. The essential conditions of exposure are: flow density incident of power radiation (radiation incident power flux density), reflection and refraction coefficients at the boundary «biological tissue-air» and between particular layers of tissue as well as wave attenuation coefficient spreading in this layers.

It was suggested to use a closed chamber to prevent problems with waves rereflection which increases procedure safety for staff and patient. Close chamber also helps to localize emission in heating limb. Chamber characteristics: length-55 cm; width-30 cm; height-40 cm; diameter-26 cm.

«SMVi-200» produces by «MedTeKo» (Russia) fusion pulse device for centimeter-wave therapy was used as a microwave generator. The apparatus operate on a frequency of 2.4 GHz in the power range from 15 to 200 W and has electronic control unit that allows to set the mode (continuous, pulse, power and time).

3. Results
Starting experiment in finding nonuniform distribution heating in capacity of phantom provided using cylindrical vessel filled with normal saline with addition of gelatin. Gelatin added in order to slowing down the convection process in vessel. The experiment had shown that gelatin doesn't allow working at a temperature little higher than room temperature as gelatin has high thermal conductivity and convection losing its gelling properties.

The Figure 4 shows examples of measured temperature distribution along the phantom while heating the phantom in microwave chamber (results of 5 measurements provided in equal conditions).
Figure 4. Distribution of values along the longitudinal axis of phantom: 1 – without microwave heating; 2,3,4,5 – in the process of microwave heating with a running time of 6 min.

As graphs in the above presented temperature nonuniform distribution while microwave radiation initiating microwave chamber with a power of 40 W on a frequency of 2.45 GHz along the phantom is unobserved. The exception is provided by zone directly adjacent to radiating element. This demonstrates that on a frequency of 2.45 GHz in the phantom made from normal saline and gelatin stationary waves are absence.

Considering that gelatin is not appropriate in further research, it had been decided to use materials similar to human tissues and having high thermal conductivity and convection. After measuring dielectric permittivity of several samples became apparent that one of appropriate materials is mincemeat of pork because of its dielectric permittivity.

In the second experiment polypropylene pipe filled with mincemeat of pork 50 cm long and with the diameter of 10 cm was used in the capacity of the phantom (Figure 5).

Figure 5. Phantom filled with mincemeat of pork

Agilent (USA) complex plane analyzer used for preliminary research shown the real part value of dielectric constant – 50 and imaginary component – 16.9. These values comparable with dimensions of human body muscle tissue [9].

Phantom was placed in microwave chamber. For preventing electromagnetic waves reemission vent of chamber was closed by flexible pipe made of radioprotective material. Experiment parameters were set using «SMVi-200» electronic display: pulse mode, power output – 40 W, heating time – 6 min.
Then heating was carried out and chamber opened after full completion. Measurement of temperature along the longitudinal axis of phantom had been produced using electronic thermometer in sequence lowering to phantom under study. Figure 6 provides results of measurements temperature distribution along the phantom without heating (1) and from exposure to microwave radiation in microwave chamber within 6 min (2,3,4). Time interval of temperature measurements between characteristic curves 2-3-4 in Figure 4 reached 13 min.

![Figure 6. Distribution of temperature values along the longitudinal axis of phantom, which was heated in microwave chamber: 1- without microwave heating in middle of phantom; 2,3,4 – in middle of phantom with microwave heating for 6 min](image)

The graph (Figure 6) shows that essential temperature nonuniform distribution while microwave radiation initiating microwave chamber with a capacity of 40 W (pulse mode) on a frequency of 2.45 GHz along the phantom is unobserved. The exception is provided by zone directly adjacent to radiating element (positioned on the right in the plane consistent with length of 55 cm according to the given scale).

4. Summary
It explains that heat field is quasihomogeneously along the line of phantom. The effect of stationary waves doesn’t appear in temperature distribution. This can be explained by temperature increase equally throughout the entire volume due to high thermal conductivity of medium. Low frequency microwave heating realized for a long period of time neutralize the known stationary waves affect.

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