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ON THE ACCURACY OF TEMPERATURE MEASUREMENT BY ELECTRONIC MEDICAL THERMOMETER WITH THERMOELECTRIC POWER SUPPLY

The paper presents the results of computer studies on the impact of thermoelectric power supply of electronic medical thermometer on the accuracy of temperature measurement. Computer simulation was used to establish the dependence of the magnitude of temperature measurement error due to the impact of thermoelectric power supply on the distance between the sensor and thermoelectric power supply. An improved design of electronic medical thermometer with thermoelectric power supply was developed.

Key words: computer simulation, thermoelectric power supply, electronic medical thermometer, accuracy of temperature measurement.

Introduction

General characterization of the problem. At the present time, measurement of body temperature in medicine is one of the first and most common factors of the level of human health. For more than 300 years somatic temperature has been measured using mercury thermometers.

Until quite recently, nearly 45 million mercury thermometers have been produced in the world annually, with 45 tons of mercury spent on their production. Sooner or later, through negligent use of thermometers they were broken, and mercury was buried in the cracks of dwelling houses or hospitals, gradually poisoning the people there. So, in recent decades, due to advances in microelectronics, electronic medical thermometers have been developed that replace mercury ones little by little.

However, it does not solve environmental problems in full measure. As power supplies for electronic thermometers, chemical galvanic elements are used which contain poisonous substances, such as alkali, lead, cadmium, mercury, zinc and nickel. According to statistics, nearly 200 million electronic thermometers have been already fabricated, whereas to assure population with such thermometers they are needed in the amount about 1 milliard pieces. That is, such amount of chemical galvanic elements must be replaced in thermometers yearly, since their service life is not more than one year, and with intensive use of thermometer, for instance, in hospital, it is considerably less. However, recycling and processing of such galvanic elements is practically absent.

Chemical galvanic elements have another disadvantage, namely in the period of their expiry date the electronic thermometer readings become unreliable. This problem is important, since thermometer readings determine immediate actions that should be taken. The foregoing implies that replacement of chemical galvanic elements and development of thermoelectric power supply for electronic thermometer owing to which the thermometer will be operated on human body heat is a problem of today [1-10]. However, no less important here is the accuracy of temperature measurement using electronic medical thermometer with thermoelectric power supply.

Therefore, the purpose of this work is to determine the impact of thermoelectric power supply of electronic medical thermometer on the accuracy of temperature measurement.

Computer simulation of the impact of thermoelectric power supply of electronic medical thermometer on the accuracy of temperature measurement

Electronic medical thermometer with thermoelectric power supply consists of three main functional units: temperature sensor, temperature recorder and thermoelectric power supply, operated on human body heat. It is common knowledge that the availability of heat sink, such as thermoelectric power supply, leads to a change in the temperature and thermal fields in the area of temperature measurement. This, in turn, reduces the accuracy of temperature measurement using such thermometer.

With a view to determine the impact of thermoelectric power supply of electronic medical thermometer on the accuracy of temperature measurement, a three-dimensional computer model of biological tissue was created, whose surface contacts the thermoelectric power supply of thermometer. The computer model was constructed with the use of Comsol Multiphysics package of applied programs [11], which allows simulating thermophysical processes in human body biological tissue with regard to blood circulation and metabolic processes. Calculation of temperature and thermal flux density distributions in the biological tissue and thermoelectric heat meter was done by finite-element method.

Computer simulation was used to determine the impact of thermoelectric power supply of electronic medical thermometer on the temperature of human skin surface under real operating conditions. Dependence of temperature measurement error on the distance between temperature sensor and thermoelectric power supply was established (Fig. 1 *a*, *b*).

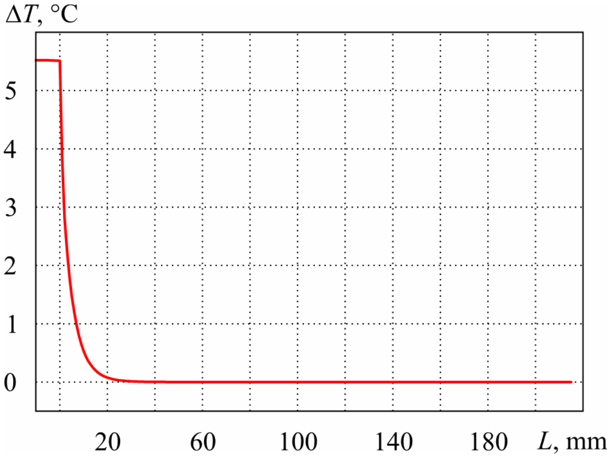
It is established that to reduce the error of human body temperature measurement using such thermometer, the distance between temperature sensor and thermoelectric power supply must be such whereby a change in human body temperature caused by thermoelectric power supply would not change the temperature of the body where temperature sensor is located.

From Fig. 1 *a* it is evident that with arrangement of temperature sensor and thermoelectric power supply on the surface of human body at the distance of $L = 2$ cm, the deviation of measured temperature value from the true one is $\Delta T = 0.1$ °C. With the distance between temperature sensor and thermoelectric power supply $L = 5$ cm the deviation of temperature is $\Delta T = 0.01$ °C (Fig. 1 *b*). Thus, the accuracy of human body temperature measurement using electronic medical thermometer with thermoelectric power supply will depend on the selection of thermometer design, that is, on the distance between temperature sensor and thermoelectric power supply.

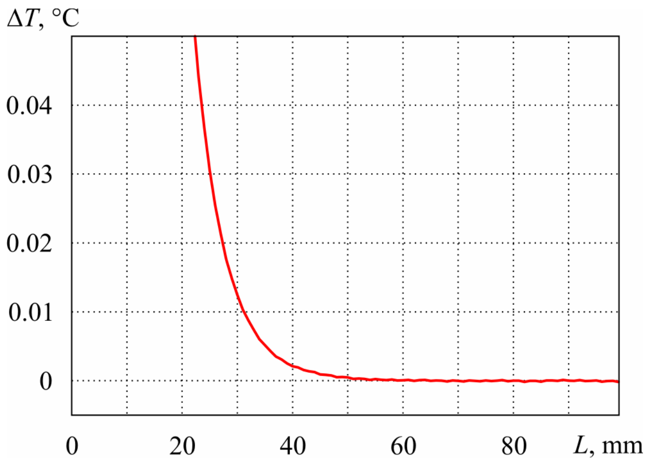
Hence it follows that, structurally, electronic medical thermometer with thermoelectric power supply must be made so that the distance between temperature sensor and thermoelectric power supply be equal to or greater than the value determined by the dependence of distance L on temperature deviation ΔT. The dependence $L(\Delta T)$ is a reciprocal function to that shown in Fig. 1 *a*. Using computer approximation of dependence $L(\Delta T)$, the following analytical form of such dependence was obtained:

$$L(\Delta T)=\left(a + c\cdot\Delta t^{0.5} + e\cdot\Delta t + g\cdot\Delta t^{1.5} + i\cdot\Delta t^{2}\right)/\left(1 + b\cdot\Delta t^{0.5} + d\cdot\Delta t + f\cdot\Delta t^{1.5} + h\cdot\Delta t^{2} + j\cdot\Delta t^{2.5}\right), \quad (1)$$

where L is the distance between temperature sensor and thermoelectric power supply, ΔT is temperature measurement error, coefficients $a = 56.667757$, $b = 55.97536$, $c = 4504.9994$, $d = 5420.2644$, $e = 193369.08$, $f = 16196.544$, $g = –62445.826$, $h = –7992.4153$, $i = –8885.923$, $j = 4548.9939$.



a)



b)

Fig. 1. Deviation of human body temperature in measurement area due to the impact of thermoelectric power supply of electronic medical thermometer a) in full range of change in temperature measurement error, b) in the range of optimal temperature measurement error (ΔT is temperature deviation (temperature measurement error), L is the distance from the edge of thermoelectric power supply of thermometer).

Design of electronic medical thermometer with thermoelectric power supply

Fig. 2 represents schematic design of electronic medical thermometer with thermoelectric power supply. Such thermometer comprises the electronic medical thermometer itself and thermoelectric power supply. In turn, the electronic medical thermometer comprises case 1, temperature sensor 2, analog-to-digital converter 3, voltage stabilizer 4, capacitor 5 and digital display 6. Thermoelectric power supply consists of two thermoelectric micromodules 7 and heat sink 8 that removes heat from the cold sides of thermoelectric micromodules 7 to the environment. Heat sink 8 is a case of material with high thermal conductivity. Temperature sensor 2 is arranged on the tip of thermally non-conductive element 9 connected to thermoelectric power supply. The length of thermally non-conductive element 9 was selected according to dependence (1) with regard to condition of non-exceeding prescribed temperature measurement error. Each thermoelectric micromodule 7 comprises a flat thermopile [1, 2] which is composed of a combination of semiconductor thermocouple elements connected into a series electric circuit, the intervals between which are filled with electrically isolating epoxy compound, and two ceramic plates closely contacting the upper and lower surfaces of thermocouple elements, as well as two electric leads. Such micromodule is made on the basis of modern high-performance thermoelectric materials based on *Bi-Te*.

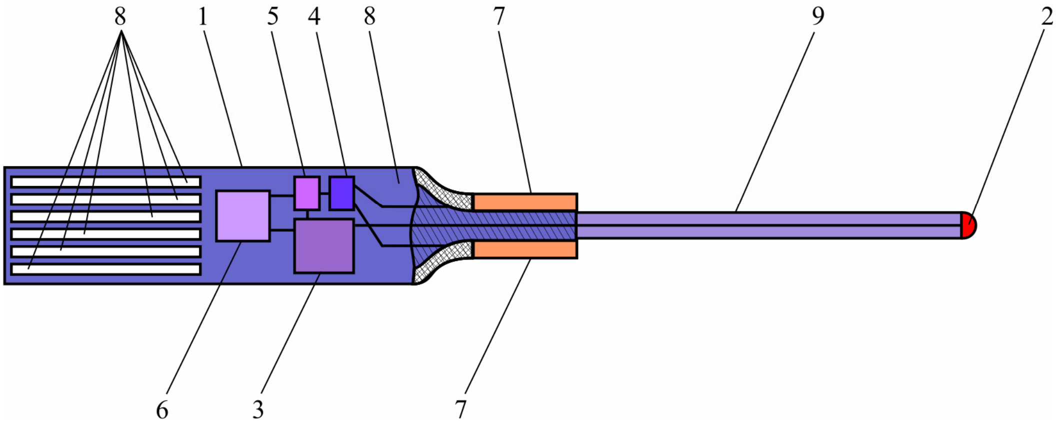


Fig. 2. Design of electronic medical thermometer with thermoelectric power supply [10]: 1 – case, 2 – temperature sensor, 3 – analog-to-digital converter, 4 – voltage stabilizer, 5 – capacitor, 6 – digital display, 7 – thermoelectric micromodules, 8 – heat sink, 9 – thermally non-conductive element.

Measurement of human body temperature using electronic medical thermometer is done by temperature sensor 2 in direct contact with human body, and electric power supply to such thermometer is assured by thermoelectric micromodules 7 due to human body heat. In order to obtain the required electric voltage and power using thermoelectric micromodules 7 for power supply to electronic medical thermometer, one should create temperature difference between the surfaces of micromodules. Application of electronic medical thermometer with thermoelectric power supply to human body (for instance, in the armpit) creates temperature gradient between the respective surfaces of thermoelectric micromodules 7 owing to which thermoelectromotive force (thermoEMF) will be generated on their leads, providing electric power supply to such device. The value of thermoEMF corresponds to the value of thermal flux passing through thermoelectric micromodules 7 whose cold sides contact heat sink 8 that removes heat to the environment. The device design also employs voltage stabilizer 4 of thermoelectric micromodules 7 to the level of 1.5 V and capacitor 5 for the accumulation of electric charge necessary for switching the electronic medical thermometer.

As compared to conventional electronic thermometer, such thermometer offers the advantage of ecological safety, as long as it comprises no chemical galvanic power supplies that require special recycling, as well as of ease of operation due to the absence of periodic replacement of power supplies. The suggested thermometer design assures increased accuracy of human body temperature measurement using electronic medical thermometer with thermoelectric power supply, the electric power supply to such thermometer being stable in time and requiring no maintenance expenses.

Conclusions

1. Using computer simulation, the impact of thermoelectric power supply of electronic medical thermometer on the accuracy of temperature measurement was determined. The dependence of the magnitude of temperature measurement error due to the impact of thermoelectric power supply on the distance between the sensor and thermoelectric power supply was established.
2. Design of electronic medical thermometer with thermoelectric power supply was developed which allows increasing the accuracy of human body temperature measurement using such thermometer.

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