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EXPERIMENTAL STUDIES OF THE ALGORITHMS FOR THE TEMPERATURE MEASUREMENT TIME REDUCING

Ua Скорочення часу під час проведення різноманітних вимірювань є одним із пріоритетних напрямків у метрології. Повною мірою це стосується і рідинних термометрів. Конструктивні методи боротьби із довготривалістю вимірювань за допомогою цього типу термометрів вичерпали себе. На часі – застосування алгоритмічних методів скорочення часу вимірювань. У статті наведені алгоритми обробки показників термометра, які дозволяють по початковій ділянці кривої розігріву знайти значення температури, яка вимірюється.

Ru Сокращение времени при проведении разнообразных измерений является одним из приоритетных направлений в метрологии. В полной мере это относится и к жидкостным термометрам. Конструктивные методы борьбы с большой длительностью измерений с помощью этого типа термометров исчерпали себя. Сейчас – время применения алгоритмических методов сокращения времени измерений. В статье приведены алгоритмы обработки показаний термометра, позволяющие по начальному участку кривой разогрева определить значение измеряемой температуры.

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Problem statement

Reducing the time when conducting a variety of measurements is one of the priority directions in metrology. The scope of the temperature measurement is not an exception. Among the many different types of thermometers, liquid thermometers are a worthwhile place. The apparent lack of power of them is the long duration of the measurement process. This duration is (3 – 4) *T*, where *T* is the time constant of the device. In the case of measuring the temperature of liquid media (the coefficient of heat transfer varies in the limits of $\alpha = 1000 - 2000\ \mathrm{Wt/m^2 \times {}^\circ}C$), the time constant is comparatively small $(T{=}0{,}1 - 20\ \mathrm{sec})$. When contacting the gas $\left(\alpha = 20 - 40\ \mathrm{Wt/m^2 \times {}^\circ}C\right)$, the value of *T* reaches 1 – 10 minutes. Constructive methods of combating this disadvantage – increasing the surface area of contact and reducing the mass of the sensing element of the thermometer – have exhausted themselves. The authors propose to reduce the measurement time algorithmically by analyzing the thermometer dissipation curve.

Analysis of recent achievements and publications

At present, there are many types of temperature sensors – liquid, gas, mechanical, electrical, thermoelectric, fiber optic, infrared, and so on – and their number grows with each passing year, thermometers appear, based on use previously not applicable to the principles of action [1, 2]. Liquid thermometers are almost the most "ancient" of their kind. Their shortcomings include the long duration of the measurement process, and this disadvantage is significant, as evidenced by the emergence of more and more new methods of reducing the measurement time [3, 4] in the thermometry. Widely used in thermometry and algorithmic methods for increasing the speed [5]. In [6], we consider the method of reducing the measurement time based on the analysis of the initial portion of the heating curve of the thermometer.

Purpose of the article

The purpose of the work is to experiment with algorithms for the processing of indications of liquid thermometers in order to reduce the time they measured the temperature.

The main part

Experimental investigations were carried out with two types of liquid thermometers – a household mercury thermometer with limits of measurements $35 - 42\ {}^\circ C$ and a price of fission $0{,}1\ {}^\circ C$, and also with a laboratory spirit thermometer with limits of measurements $0-100\,°C$ and a price of division $1{,}0\,°C$ (fig. 1).

Fig. 1. To the right is a mercury thermometer, on the left is an alcohol thermometer

Thermometers measured the temperature of some objects (mercury – the temperature of the human body, alcohol – the temperature of the container with heated water). Indications of the mercury thermometer were taken at intervals of 0 – 192 seconds in 12 seconds, indications of alcohol thermometer – in the interval 0 – 175 sec in 5 seconds increments. Dependences of thermometer readings on time are shown in fig. 2.

The differential equation describing the process of heating the thermometer has the form [2]

$$mcdt = \alpha F(t_n - t)d\tau, \qquad (1)$$

where m – is the mass of the sensing element of the thermometer, c – is its specific heat capacity, α – is the heat transfer coefficient, F– is the contact area of the sensing element, t_n is the measured temperature, t– is the current temperature value, τ– is the current value of the time.

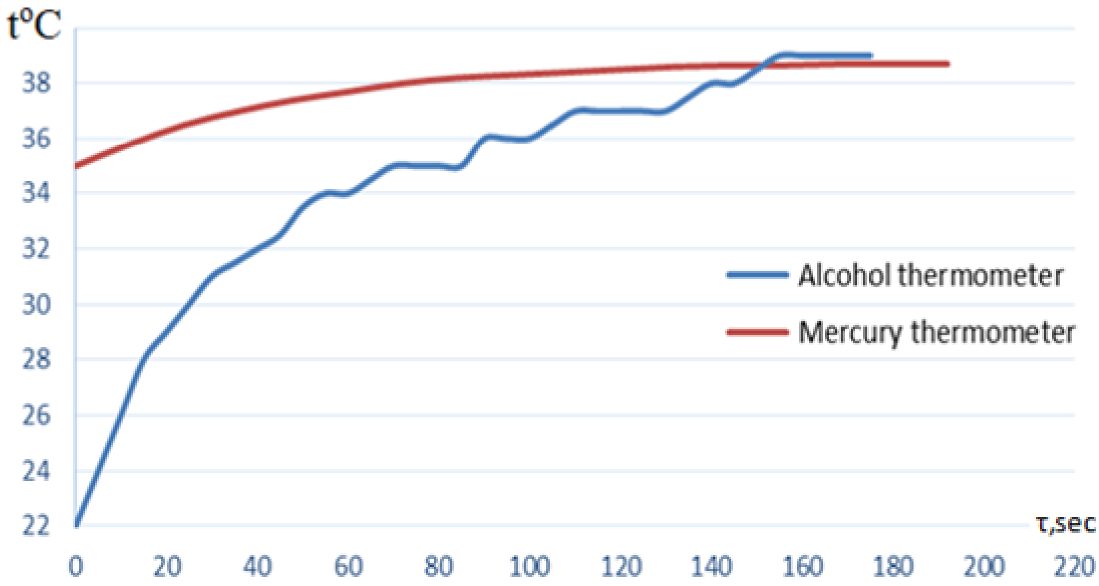

Fig. 2 Dependence of thermometer readings on time

The solution of equation (1) under initial conditions τ = 0, $t = t_{env}$ and the notation $\beta = \alpha F m^{-1} c^{-1}$, is written as follows:

$$t_m = t_{env} \times e^{-\beta\tau} + t_n \times (1 - e^{-\beta\tau}). \tag{2}$$

Minimize the squareness of the discrepancy between the real value of the temperature t_{env} and the corresponding calculated value of tm as shown in fig. 3

$$f(\beta, t_n) = \frac{1}{n}\sum (t_r - t_m)^2 = \frac{1}{n}\sum \left[t_r - t_{env} e^{-\beta\tau} - t_n \left(1 - e^{-\beta\tau}\right) \right]^2, \tag{3}$$

Taking the ranges of possible values of $\beta = 0{,}002 - 0{,}042$ sec^{-1}, t_n=35 – 42°C, for a mercury thermometer, we calculate the values of the functional $f(\beta,\ t_n)$ with the step $\Delta_\beta = 0{,}001$, sec^{-1} and $\Delta_{t_n} = 0{,}1\ °C$, and find it minimum, and thus we determine the "best" estimates of the parameters β and t_n. Table 1 shows the values of the functional $f(\beta,\ t_n)$ for various values of β and t_n near the point of its minimum.

***Table* 1.**

The dependence of the residual f on the parameters t_n and β for a mercury thermometer near the point of minima

t^oC / β sec^{-1}	38,5	38,6	38,7	**38,8**	38,9	39	39,1
0,016	0,220478	0,160163	0,110578	**0,071723**	0,043599	0,026204	0,01954
0,017	0,171468	0,117406	0,074499	**0,042748**	0,022152	0,012711	0,014426

t^oC / β sec^{-1}	38,5	38,6	38,7	**38,8**	38,9	39	39,1
0,018	0,132423	0,084305	0,047735	**0,022713**	0,009238	0,007311	0,016931
0,019	0,101605	0,059124	0,028554	**0,009893**	0,003142	0,0083	0,025368
0,02	0,077606	0,040464	0,015565	**0,002912**	0,002502	0,014336	0,038415
0,021	**0,05928**	**0,027188**	**0,007649**	**0,000664**	0,006233	0,024355	0,055032
0,022	0,045689	0,018372	0,003895	0,002259	0,013464	0,037509	0,074395
0,023	0,03606	0,013258	0,003563	0,006975	0,023494	0,05312	0,095853
0,024	0,029753	0,011223	0,006047	0,014226	0,035758	0,070645	0,118886

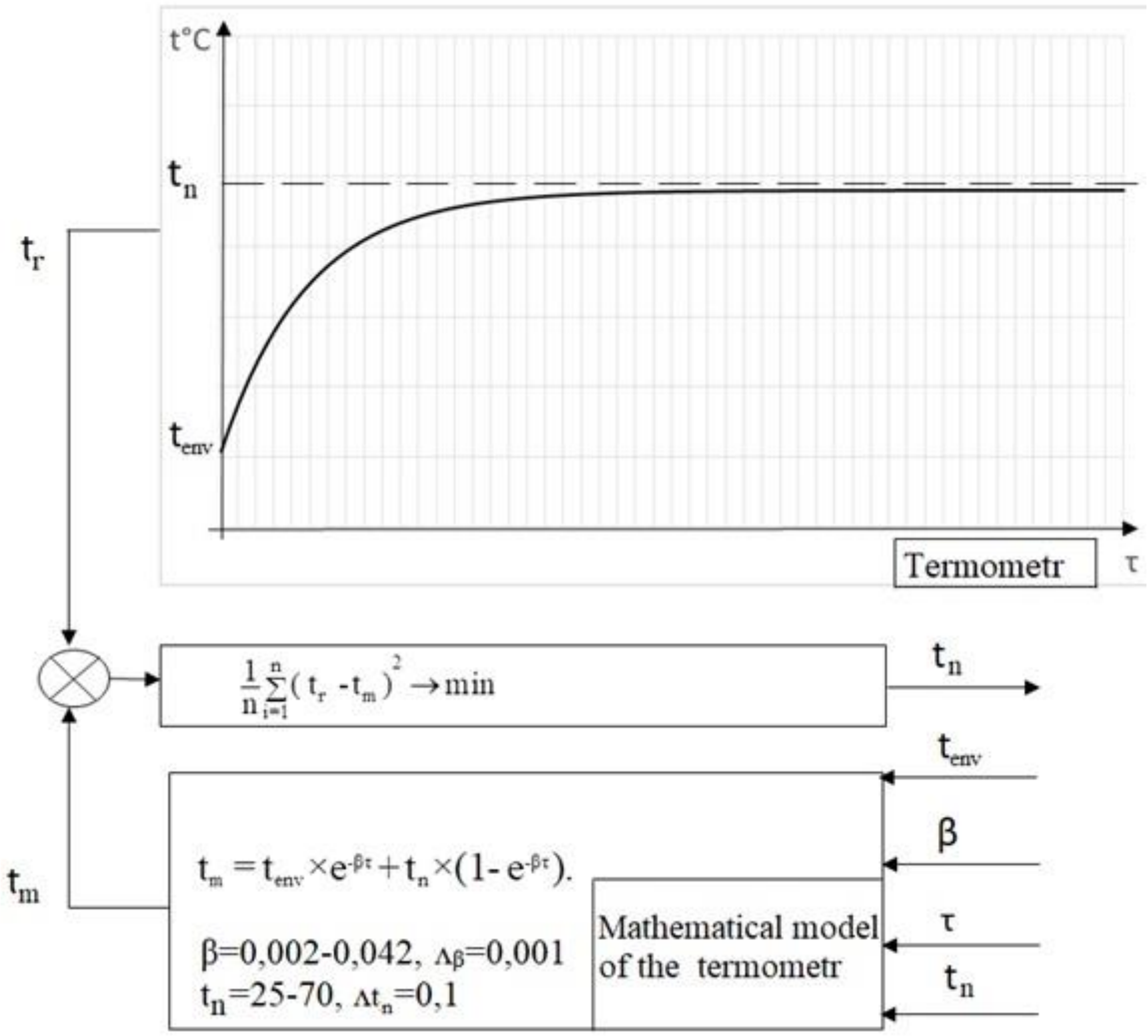

Fig. 3. Scheme of the experiment

As can be seen from table 1, the minimum value of the functional $f_{min}(\beta, t_n) = 0,000664$ degrees^2 takes place at $\beta = 0,021\,\sec^{-1}$ and $t_n = 38,8°C$. These values, and above all the value of t, will be considered true, corresponding to the real process. Since the key point in finding the true parameter values is to find the minimum of the sum of the failures (3), consider several ways to implement this process. The application of the method of the co-ordinate descent and the method of the fastest descent made it possible to determine the true values of the parameters β and t_n and the minimum value of the sum of the squares of the residual $f_{min}(\beta, t_н) = 0,01094$ degrees^2, however the number of iterations from the starting point $\beta = 0,011\,\sec^{-1}$ and $t_n = 35,2\,°C$ at the same time significantly differed (fig. 4).

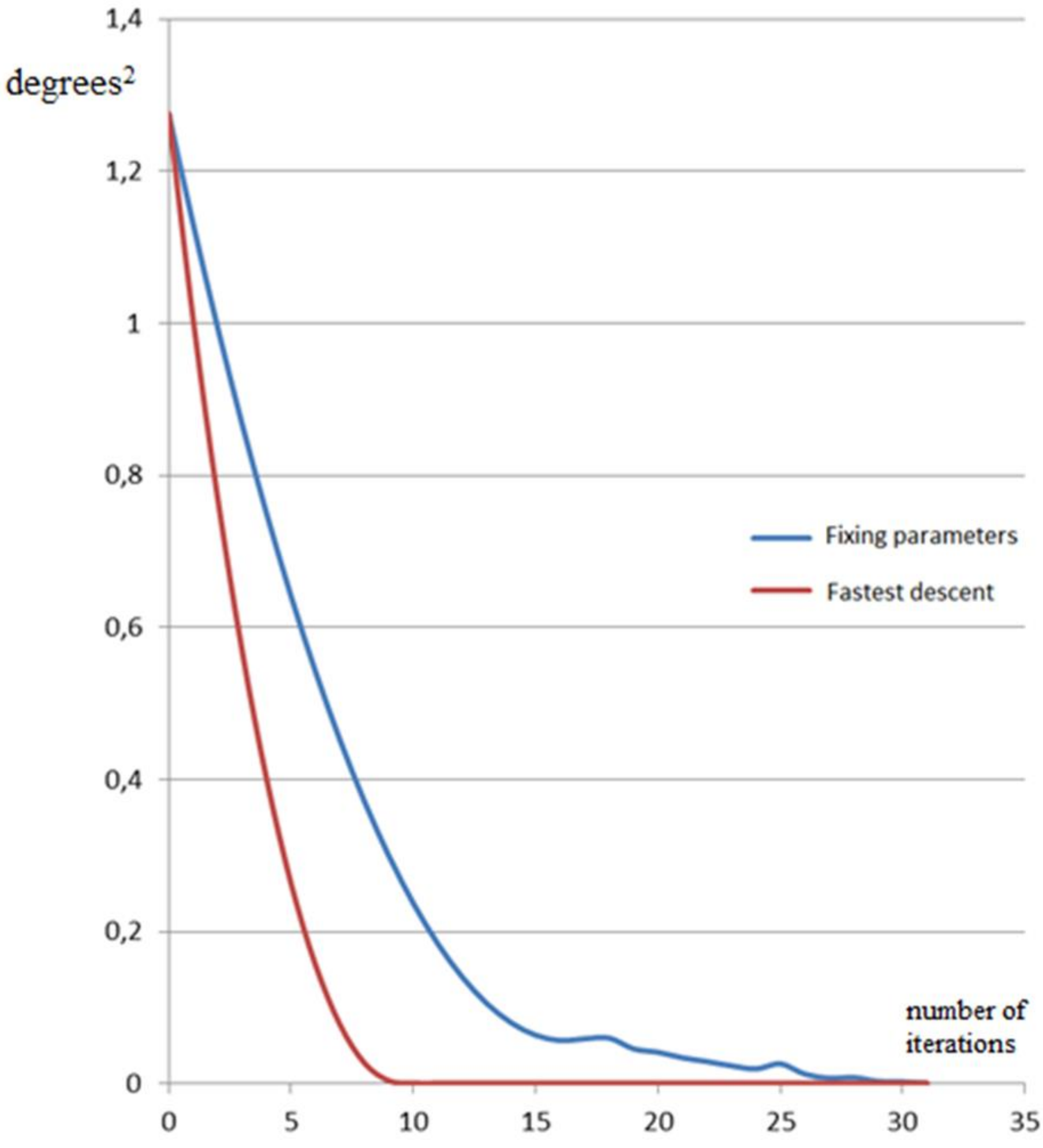

Fig. 4. Comparison of the method of co-ordinate descent and the method of the fastest descent

In addition, another method has been tested for minimizing the sum of squares of discrepancies. Its essence is that. In the case where the coefficient β depending on the design features of the thermometer – is known, it is possible, by minimizing the functional (3), to calculate the measured temperature *t*, thus:

$$t_n = \left[\Sigma t \left(1 - e^{-\beta\tau}\right) - t_{env} \Sigma e^{-\beta\tau} \left(1 - e^{-\beta\tau}\right) \right] \left[\Sigma \left(1 - e^{-\beta\tau}\right)^2 \right]^{-1} . \quad (4)$$

Liquid thermometers are intended for the most part to measure steady–state temperature, therefore, the coefficient β is generally unknown. It enters the expression (3) – nonlinear, and it is not possible to obtain a dependence in the form of a formula analogous to expression (4). Therefore, the following sequence of steps is proposed:

– for each value $\beta = 0,002 - 0,042$, the value of temperature t_n is calculated from the range of its possible changes with the selected step $\Delta_\beta = 0,001$ according to formula (4),
– then for each pair of the assigned value of β and the calculated value of t_n, by the formula (3), the sum of squares of discrepancies is calculated,
– the minimum value of the functional (3) is sought, to which the "best" estimates of the parameters β and t_n correspond.

The results of the minimum search using this technique for a mercury thermometer are presented in table 2.

***Table* 2.**

The dependence of the residual f on the parameters t_n and β for a mercury thermometer near the point of minima

β, c^{-1}	$t_н$, °C	f, degrees^2
0,002	50,01052	8,721184
0,003	45,75181	7,526189
0,004	43,63918	6,447321
0,005	42,38402	5,479238
0,016	39,11211	0,330845
0,017	39,03463	0,204723
0,018	38,96669	0,113389
0,019	38,90669	0,052955
0,02	38,85335	0,019878
0,021	**38,80564**	**0,010945**
0,022	38,76274	0,023249
0,023	38,72397	0,054174
0,024	38,68876	0,101366
0,025	38,65665	0,162719

β, c^{-1}	$t_н$, °C	f, degrees^2
0,04	38,37851	1,881602
0,041	38,36751	2,013655
0,042	38,35705	2,145406

And finally, the main question is: how much time can be reduced to collect information to get a reliable answer about the measured temperature of the medium.

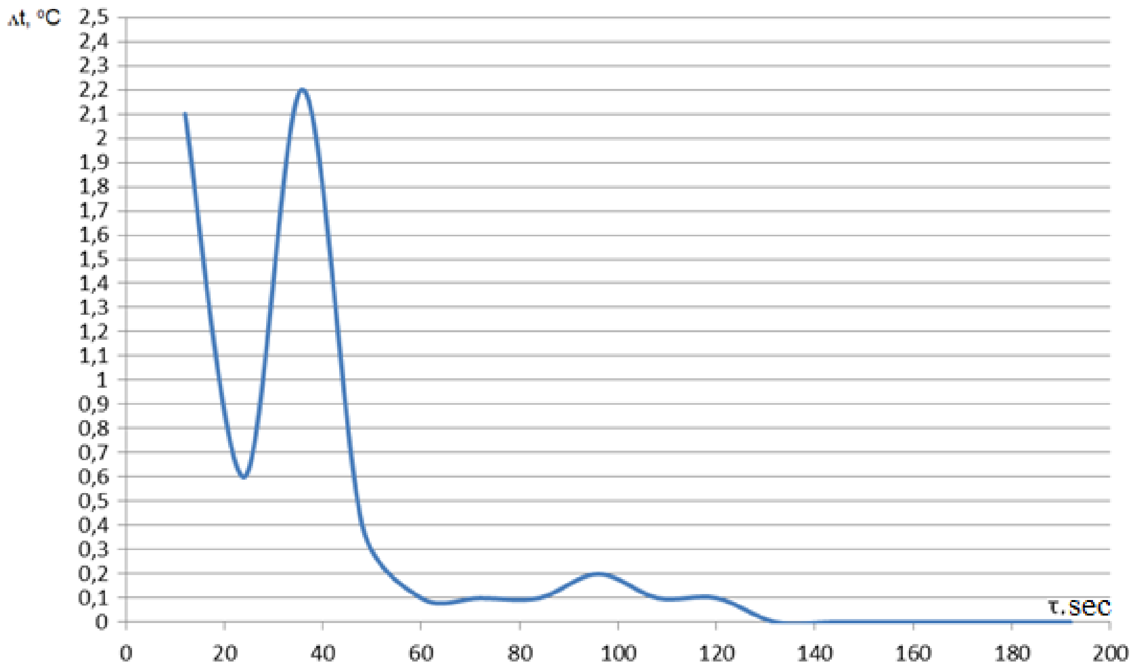

Fig. 5. Dependence of the error of calculation of temperature t with mercury thermometer from the time of the set of information

Assuming that the law of changing thermometer readings has the form (2), measuring the initial value of temperature t_{env} and applying the least squares method to the actual process, the values of estimates of the parameters t_n and β were obtained depending on the time of the set of information. As an error, we considered the difference between the values of the obtained estimate of the temperature for a given value of the time interval and its true value obtained as a result of processing the entire heating curve. The results are shown in fig. 5 and fig. 6. It follows from the figures that for an alcohol thermometer, the error does not exceed $1°C$ after the 135-th second of measurement, and for a mercury thermometer, the error does not exceed $0{,}1°C$ after the 108-th second. In addition, in the case if the speed of obtaining a "rough", estimated result is important, then for an alcohol thermometer the error will not exceed $2°C$ after the 95-th second measurement, and the mercury error will not be greater than $0{,}2°C$ after the 48-th seconds.

Findings

1. The article proposes a method for measuring the temperature of liquid thermometers, based on the analysis of the initial portion of the thermometer heating curve.

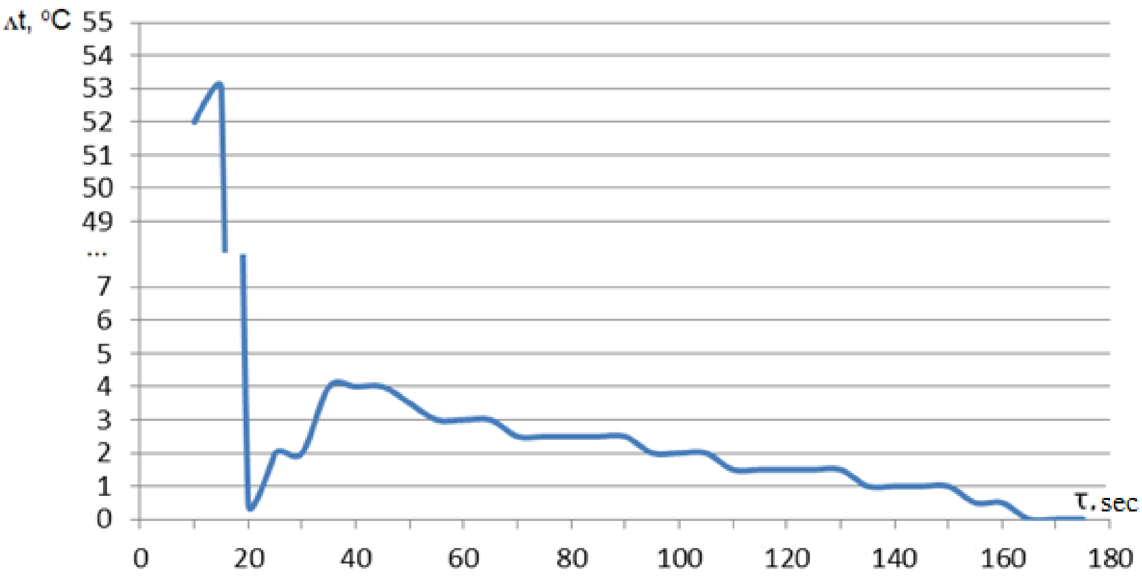

Fig. 6. The dependence of the error in calculating the temperature t with an alcohol thermometer on the time of information gathering

2. A comparative analysis of algorithms that can be used to implement this method has been carried out.
3. For two types of thermometers – a mercury thermometer with a measuring range of $35-42°C$ and a dividing price of $0{,}1°C$, and an alcohol one with a measuring range of $0-100\,°C$ and a dividing cost of $1{,}0°C$, the method and algorithms are evaluated.
4. From the analysis of the initial sections of the heating curves of real thermo–meters it was concluded that it is advisable to use this technique.

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