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Analysis of the temperature component of the combined standard uncertainty of the refractive index according to the test data of the control system for meteorological parameters developed for the Lyptsi geodetic polygon

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Abstract

The National Scientific Centre "Institute of Metrology" is actively involved in the implementation of a number of international projects under the EMPIR programme. One of such joint projects is the EMPIR 18SIB01 GeoMetre research project "Large-scale dimensional measurements for geodesy". The overall goal of the project is to ensure traceability of length measurements – from the measurement standard of the unit of length to long distances typical for geodetic measurements. As a result of the project, it is necessary to provide length measurements of at least 5 km with an expanded uncertainty of no more than 1 mm.

The main task of the NSC "Institute of Metrology" within this project is the development, research and practical implementation of methods and means of accounting for the influence of the earth's atmosphere on the results of measurements of long distances in geodesy, carried out using electromagnetic waves in the optical range.

When performing the section Task 1.4 of the project, new methods of highly accurate determination of the mean integral refractive index of air, used as a correction taking into account the influence of the atmosphere on the measurement results, are justified. Requirements for the accuracy of measurements of meteorological parameters at discrete points of the baseline are formulated, which are necessary to determine the mean integral refractive index. That is, the requirements for the metrological characteristics of temperature, pressure and humidity sensors are determined.

The article discusses the results of the development, manufacture and testing of the sensors for temperature measurement. It is shown that the created sensors meet the requirements of the GeoMetre project.

Keywords: geodesy; length measurement; refractive index of air; temperature sensor.

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Introduction

During the implementation of Task 1.4 of the GeoMetre project, [1] the need to develop a temperature measurement control system was substantiated, allowing to perform real-time measurements (synchronously with the measurement of distances to fixed points at the geodetic polygon of NSC "Institute of Metrology" in Lyptsi) with an accuracy that meets the requirements formulated in the framework of Task 1.4 of the project JRP – 18SIB01 GeoMetre [2, 3].

Statement of basic material

To solve this problem, a measuring complex was designed, which is based on a temperature sensor (microcircuit manufactured by Texas Instruments TMP117), which can serve as a single-chip digital alternative to Platinum RTD (Resistance temperature detectors) and has an accuracy comparable to class AA RTD [4] (Fig. 1), and a system that provides the accumulation and transfer of measured data to the base station (Fig. 2).

To obtain the results necessary to evaluate the accuracy characteristics of this complex, studies of temperature sensors were initially carried out using a reference setup for reproduction of the Ga melting point (gallium melting point) [5].

In the course of the research, the reproduced Ga melting point temperature was repeatedly measured by all sensors included in the measuring complex in order to collect statistics necessary to evaluate the type A and type B uncertainty components for each sensor.

Type A uncertainty for the *i*-th sensor was determined by the formula [6]:

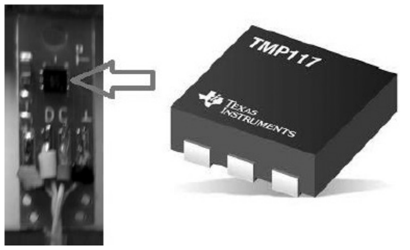

Fig. 1. A prototype of the temperature determination system

Fig. 2. Manufactured version of the system for collecting and transfer measurement information on the air temperature in the field conditions

$$u_{Ai} = \sqrt{\frac{\sum_{j=1}^{n}\left(t_{ji} - t_{me\ i}\right)^2}{n(n-1)}}, \quad (1)$$

where t_{ji} is the temperature measured by the i-th sensor at j-th reading (j is number of the reading in the measurement), $t_{me\,i}$ is the mean temperature measured by the i-th sensor for n readings.

Type B uncertainty for the i-th sensor was determined by the formula:

$$u_{Bi} = \left|\frac{t_r - t_{me\ i}}{\sqrt{3}}\right|, \quad (2)$$

where t_r is the reference melting point of gallium.

The combined standard uncertainty for the i-th sensor was calculated by the formula:

$$u_{Ci} = \sqrt{u_{Ai}^2 + u_{Bi}^2}. \quad (3)$$

The results are presented for an array of n = 30 observations (readings) performed using sensors No. 0, 1, 2, 3 in Table 1.

Using the requirements for the accuracy of sensors taken from the Report on Task 1.4.1 of the project JRP – 18SIB01 GeoMetre, after recalculating them in relation to the conditions of these studies, i.e., for T = 303.15 K, a graph was obtained (see Fig. 3), which shows both the specified requirements (yellow zone) and the obtained maximum limits for the combined standard uncertainty of the sensors (green zone).

Next, the temperature component of the combined standard uncertainty of the determination of $\overline{n}$ was evaluated as part of a field experiment at the Lyptsi polygon [7].

The combined standard uncertainty evaluation of the results of measurement performed on 01 June, 2021, using a complex of four created sensors at NSC "Institute of Metrology" reference polygon, was carried out in the following form:

– type A uncertainty for i-th sensor

$$u_{Ai\ r} = \sqrt{\frac{\sum_{j=1}^{m}\left(t_{jir} - t_{me\ ir}\right)^2}{m(m-1)}},$$

where j is the number of a reading; m is the amount of readings in a measurement; t_{jir} is the temperature measured at j-th reading by i-th sensor at the reference polygon; $t_{me\,ir}$ is the mean temperature for i-th sensor at the reference polygon at m readings;

– type B uncertainty: obtained during preliminary studies and is equal to u_{Bi} from Table 1;

Table 1

The results of research of measurement uncertainty characteristics for sensors No. 0, 1, 2, 3

Uncertainty \ Sensor number	$i = 0$	$i = 1$	$i = 2$	$i = 3$
u_{Ai}	0.002	0.003	0.002	0.001
u_{Bi}	0.006	0.005	0.007	0.023
u_{Ci}	0.007	0.006	0.007	0.023

Table 2

The result of the evaluation of the combined standard uncertainty

Uncertainty \ Sensor number	$i = 0$	$i = 1$	$i = 2$	$i = 3$
$u_{Bi\,r}$	0.006	0.005	0.007	0.023
$u_{Ai\,r}$	0.003	0.003	0.003	0.006
$u_{Ci\,r}$	0.007	0.006	0.007	0.024

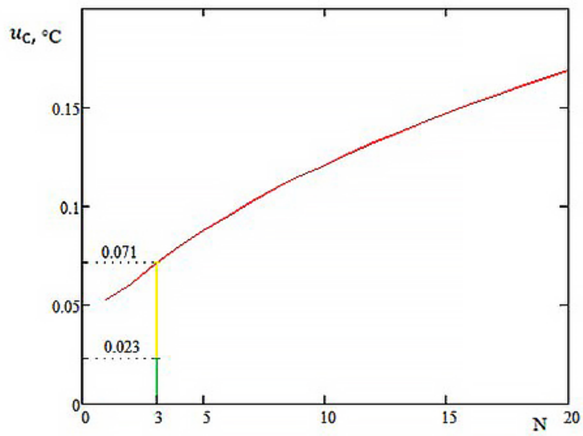

Fig. 3. Illustration of compliance of the maximum combined standard uncertainty of the studied sensors (green zone) with the requirements set at stage A.1.4.1 (yellow zone)

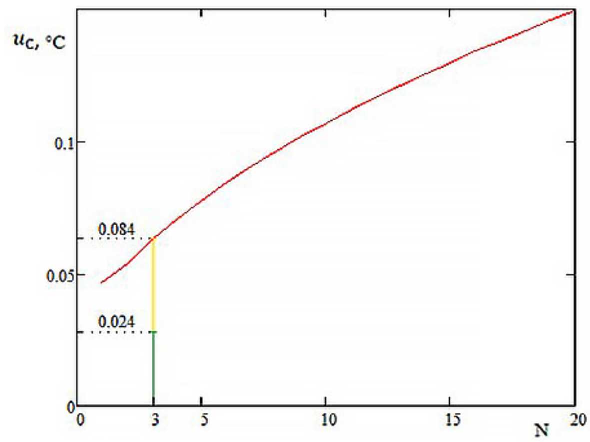

Fig. 4. Illustration of the compliance of the combined standard uncertainty of each *i*-th sensor during the experiment at the Lyptsi polygon (green zone) with the requirements formulated at stage A.1.4.1 (yellow zone)

– the combined standard uncertainty of the *i*-th sensor: $u_{Ci\ r} = \sqrt{u^2_{Ai\ r} + u^2_{Bi}}$.

Uncertainty evaluation for each sensor was carried with a 2-minute time interval, temperature readings were taken on ceper second. According to [8], for a time T 2 min, which does not exceed the time of one reading during long distance measurements, the mean temperature value under normal climatic conditions cannot change by more than 0.005...0.01 °C. That is, the obtained value of the mean integral refractive index of air will correspond to the results of measurements with a rangefinder (tacheometer), taking into account the requirements for the accuracy of such measurements.

Results are shown in Table 2.

Applying the requirements of Task 1.4.1 of the project JRP – 18SIB01 GeoMetre to the sensors and recalculating them for the conditions of the experiment, we obtain the graph shown in Fig. 4, from which it follows that the sensors meet the previously substantiated requirements.

Next, the evaluation of the relative contribution of the temperature measurement uncertainty component to the combined standard uncertainty of the refractive index determination is performed [2]. The purpose of this evaluation is to verify the compliance of the accuracy characteristics of the measured quantity with the values approved at stage 1.4.1 when forming the accuracy requirements, namely:

$$u_{nt\ r} < \sqrt{0.1 \cdot 10^{-14}} \approx 0.3 \times 10^{-7}.$$

The temperature uncertainty contribution is evaluated by the formula:

$$u_{nt\ r} = \sqrt{\begin{aligned}&\left(\frac{1}{6}\frac{dn_0}{dt_0}u_{C0\ r}\right)^2 + \left(\frac{1}{6}\frac{dn_3}{dt_3}u_{C3\ r}\right)^2 + \\ &+\left(\frac{1}{3}\frac{dn_1}{dt_1}u_{C1\ r}\right)^2 + \left(\frac{1}{3}\frac{dn_2}{dt_2}u_{C2\ r}\right)^2\end{aligned}}, \quad (4)$$

where $\dfrac{dn_i}{dt_i}$ is the partial derivative of Siddor's formula [9, 10] with respect to temperature at the temperature determined by the *i*-th sensor; $u_{Ci\ r}$ is the combined standard uncertainty of the *i*-th temperature sensor.

The uncertainty component of the temperature measurement in the refractive index uncertainty is determined as:

$$u_{nt\ r} = 5.3 \times 10^{-9}.$$

That is, the requirements of stage 1.4.1. in terms of temperature measurements have been fulfilled $\left(5.3 \times 10^{-9} < 0.3 \times 10^{-7}\right)$.

Conclusion

The manufactured sensors meet the requirements for the accuracy of temperature measurements formulated during performing Task 1.4.

Since the requirements for the accuracy of measurements of pressure, humidity and the gradient of the refractive index of air at the end points of the baseline, formulated in Task 1.4, are less stringent than the requirements for temperature sensors, it can be considered that the main requirement of the GeoMetre project – to ensure the measurement of the baselines of up to 5 km with expanded uncertainty of no more than 1 mm – will be successfully completed after the development of the rest equipment for meteorological measurements.

Acknowledgement

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Аналіз температурної складової сумарної стандартної невизначеності показника заломлення за даними випробувань системи контролю метеопараметрів, створеної для Липецького геодезичного полігону

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Анотація

Національний науковий центр "Інститут метрології" бере активну участь у виконанні ряду міжнародних проєктів за програмою EMPIR. Одним із таких спільних проєктів є дослідницький проєкт EMPIR 18SIB01 GeoMetre "Large-scale dimensional measurements for geodesy". Загальною метою проєкту є забезпечення простежуваності вимірювань довжини – від еталона одиниці довжини до великих довжин, характерних для геодезичних вимірювань. У результаті виконання проєкту необхідно забезпечити вимірювання відстаней не менше 5 км з розширеною невизначеністю не більше 1 мм.

Основним завданням, яке виконує ННЦ "Інститут метрології" у рамках цього проєкту, є розробка, дослідження та практична реалізація методів і засобів обліку впливу земної атмосфери на результати вимірювань великих довжин у геодезії, які здійснюються за допомогою електромагнітних хвиль оптичного діапазону. При виконанні розділу Task1.4 проєкту були обгрунтовані нові методи високоточного визначення середньоінтегрального показника заломлення повітря, який використовують в якості поправки, що враховує вплив атмосфери на результати вимірювань. Сформульовано вимоги до точності вимірювань метеопараметрів у локальних точках траси, необхідних для визначення середньоінтегрального показника заломлення. Тобто, визначені вимоги до метрологічних характеристик давачів температури, тиску і вологості повітря.

У статті розглядаються результати розробки, виготовлення і випробувань давачів для вимірювання температури. Показано, що створені давачі задовольняють вимогам проєкту GeoMetre.

Ключові слова: геодезія; вимірювання довжини; показник заломлення повітря; давач температури.

Анализ температурной составляющей суммарной стандартной неопределенности показателя преломления по данным испытаний системы контроля метеопараметров, созданной для Липецкого геодезического полигона

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Аннотация

Национальный научный центр "Институт метрологии" активно участвует в выполнении ряда международных проектов по программе EMPIR. Одним из таких совместных проектов является исследовательский проект EMPIR 18SIB01 GeoMetre "Large-scale dimensional measurements for geodesy".

Основной задачей, которую выполняет ННЦ "Институт метрологии" в рамках данного проекта, является разработка, исследование и практическая реализация методов и средств учета влияния земной атмосферы на результаты измерений больших длин в геодезии, осуществляемых с помощью электромагнитных волн оптического диапазона. При выполнении раздела Task 1.4 проекта были обоснованы новые методы высокоточного определения среднеинтегрального показателя преломления воздуха, используемого в качестве поправки, учитывающей влияние атмосферы на результаты измерений. Сформулированы требования к точности измерений метеопараметров в дискретных точках трассы, необходимых для определения среднеинтегрального показателя преломления.

В статье рассматриваются результаты разработки, изготовления и испытаний датчиков для измерения температуры. Показано, что созданные датчики удовлетворяют требованиям проекта GeoMetre.

Ключевые слова: геодезия; измерение длины; показатель преломления воздуха; датчик температуры.

References

1. GeoMetre (JRP 18SIB01). Large-scale dimensional measurements for geodesy. Annex 1, v.2.0. Available at: https://www.ptb.de/empir2019/geometre/
2. Neyezhmakov P., Kupko V., Panasenko T., Prokopov O., Skliarov V., Shloma A. Analysis of accuracy requirements to the meteorological sensors used to compensate for the influence of the Earth's atmosphere in high precision length measurement. Proceedings of SMSI 2020 Conference – *Sensor and Measurement Science International*. Nuremberg, Germany, June 2020, pp. 279–280. doi: 10.5162/SMSI2020/D3.3
3. Neyezhmakov P., Prokopov O., Panasenko T., Skliarov V., Shloma A. Towards the assessment of the accuracy of measuring the integral characteristics of physical quantities using the sensors of discrete values of these quantities. Proceedings of SMSI 2021 Conference – *Sensor and Measurement Science International*. Nuremberg, Germany, May 2021, pp. 310–311. doi: 10.5162/SMSI2021/C9.2
4. Specification is available at: http://datasheetspdf.com/pdf/1405797/etc TI/TMP117/1
5. Ivanova E.P., Yunakov I.N., Fil S.V. Regionalnyye slicheniya pervichnykh etalonov yedinitsy temperatury v oblasti kontaktnoy termometrii [Regional comparisons of the primary measurement standards of the unit of temperature in the field of contact thermometry]. Proceedings of the *VIII International Scientific and Technical Conference "Metrology and Measuring Techniques"*. Kharkiv, 2012, pp. 276–280 (in Russian).
6. JCGM 100:2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement. JCGM, 2008. 120 p.
7. Kupko V., Prokopov O., Lukin I., Sobol V., Kosenko O., Kofman O. Natsionalnyi etalonnyi liniino-heodezychnyi polihon [The national reference linear geodetic polygon]. Modern achievements of geodesic science and industry: collection of scientific works. Lviv, 2004, pp. 98–104 (in Ukrainian).
8. Reshetov V.D. Izmenchivost meteorologicheskikh elementov v atmosphere [Variability of meteorological elements in the atmosphere]. Leningrad, Gidrometeoizdat, 1973. 216 p. (in Russian).
9. Ciddor P.E. Refractive index of air: new equations for the visible and near infrared. *Applied Optics*, 1996, vol. 35(9), pp. 1566–1573. doi.org/10/1364/AO.35.001566
10. Ciddor P.E., Hill R.J. Refractive index of air: 2. Group index. *Applied Optics*, 1999, vol. 38(9), pp. 1663–166. doi.org/10.1364/AO.38.001663