DOI: 10.5604/01.3001.0015.9095
Volume 111 • Issue 1 • March 2022

Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Gas temperature meter

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ABSTRACT

Purpose: of the article is to develop a digital portable gas temperature meter in the range of -50…+600°C. To measure the temperature of dusty gas flows in the air pollution sources with the least significant digit of the digital device 1°C.

Design/methodology/approach: The microprocessor measuring unit, probe and software is proposed. It leads to build a high-precision temperature meter based on a thin film sensor HM220 type "pt100".

Findings: The calculation of the electrical schematic diagram parameters for signal conditioning of the sensor relative to the input range of the analog-to-digital converter. The experimental measuring unit and the probe of the gas temperature meter are assembled. The principle of the gas temperature meter calibration with the help of a precision resistance box MSR-60M is considered. The experimental gas temperature meter has a total standard uncertainty determined by type B for a maximum value of the measurement range of 1.94°C. The error of the sensor "pt100" makes the largest contribution to the total standard uncertainty, so the error increases in proportion to the value of the measured temperature.

Research limitations/implications: On the basis of the proposed design of gas temperature meter it is possible to construct devices with various lengths of probes.

Practical implications: The proposed meter is designed for environmental laboratories that measure the velocity, flow and sampling of dust and gas emissions from sources of air pollution.

Originality/value: The device design differs due to the use of thermostable wire made of constantan as extending conductors of the temperature sensor, which is included in the unbalanced Wheatstone bridge. This solution allows the use of unipolar power supply 3.3 V for both analog and digital part of the meter. Temperature meter based on a thin film resistance thermometer is characterized by relative ease of manufacture, low material consumption, cost and high reliability.

Keywords: Meter, Temperature, "pt100", Thermal converter, Sensor, Probe

Reference to this paper should be given in the following way:

N.M. Zashchepkina, M.P. Svyta, Gas temperature meter, Journal of Achievements in Materials and Manufacturing Engineering 111/1 (2022) 33-41. DOI: https://doi.org/10.5604/01.3001.0015.9095

MANUFACTURING AND PROCESSING

1. Introduction

The measurement of temperature samples of gases is of particular importance in ecological research. Measurement is necessary to calculate the density, velocity, flow rate, volume of gases and bring the results to normal conditions, etc. [1-4].

Measurements can be performed by contact and contactless methods. Contact thermometers are used to monitor the temperature of emissions into the atmosphere from pollution sources. Contact thermometers are based on thermocouples or platinum resistance thermal converter. Resistance thermal converters are used to measure temperatures up to 850°C, and thermocouples are used above 850°C [5]. Platinum resistance thermal converter, in comparison with thermocouples, have standardized passport characteristics [6,7]. Nominal static characteristics and error are defined in the operating temperature range, which simplifies the manufacture and adjustment of temperature meters. Resistance thermal converters are manufactured using wire-wound and thin film technologies [8].

Contact temperature meters, based on thin-film resistance thermometers of various designs and constructions, are characterized by relative ease of manufacture, low material consumption, cost, high reliability and fault with standability. The most common platinum resistance thermal converter of this class are resistance thermometers of the "pt100" type with a nominal resistance value of 100 Ohms at a temperature of 0°C.

The temperature of dusty gas flows can reach 600°C during measuring temperature. Measurements are performed at flow velocities up to 20 m/s and a chimney wall thickness up to 1 m. This puts forward additional requirements for the stability of the temperature probe design to vibration.

Manufacturers of platinum temperature sensors propose designs with and without extension wires. The maximum operating temperature of the sensor with extension wires with fiberglass insulation is 400°C.

In the article [9] the scheme of inclusion of a thin-film temperature sensor on a 2-wire circuit in Wheatstone bridge with thermostable conductors without thermal compensation of connecting wires is substantiated. The normalization principle of analogue signal for measurement of temperatures in the range -50...+300°C, with application of ratiometric power supply of the scheme is proposed. It is proposed to use a constantan wire with a diameter of 0.5 mm as a thermostable conductor.

We apply the above principle to implement a temperature meter in the range -50…+600°C. Assemble an experimental probe of the meter with a length of 1 m, based on a constantan wire with a diameter of 0.8 mm, to reduce the probe resistance. As a temperature sensor it was used a miniature platinum sensor type "pt100" HM220 of company Heraeus (Germany) with a temperature coefficient of 3850 ppm/K [10]. The measuring range of this sensor is –70...+600°C, dimensions 2.3x1.9x0.9 mm.

<u>The purpose and objectives of the study</u>

Development of a digital portable gas temperature meter in the range of -50…+600°C, with the least significant digit of the digital device 1°C for measuring the temperature of dusty gas flows in the air pollution sources.

To achieve this goal, the following tasks were formulated and solved:

- development of a measuring unit for operation in the temperature range -20…+40°C;
- selection and calculation of elements of the gas temperature meter circuit;
- development of a probe for a gas temperature meter based on a sensor type "pt100" HM220 in the temperature range -50…+600°C;
- calibration of the temperature meter in the operating range -50...+600°C using the resistance box MSR-60M;
- analysis of the temperature measurement error of the proposed meter.

2. Materials and methods

The principle of meter operation is based on the conversion of the platinum sensor type "pt100" resistance in the indication of the temperature value on a seven-segment liquid crystal display in °C.

In Figure 1 is presented a block diagram of a gas temperature meter, which shows the principle of converting the sensor resistance into temperature values displayed on the liquid crystal display. The block diagram consists of a temperature sensor, a conditioning amplifier, a low-pass filter, a microcontroller with a built-in analog-to-digital converter (ADC) and a liquid crystal display.

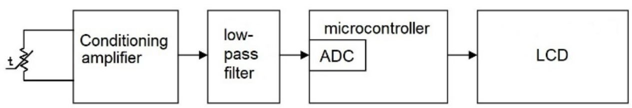

Fig. 1. Block diagram of the gas flow temperature meter

The electrical schematic diagram of the portable meter is presented in Figure 2. The meter is powered by a nine-volt battery. The battery connects to the J1 connector. The analog and digital parts of the circuit are powered by a 3.3 V degenerative voltage stabilizer U1 MCP1703AT-3302, which is also the ADC reference voltage. So, the ADC code will not depend on the temperature drift of the voltage stabilizer U1 [11]. The analog part contains a selected temperature sensor HM220, which is included in the unbalanced measuring Wheatstone bridge assembled on resistors R_3-R_5. The conditioning amplifier U3 is assembled on a precision rail-2-rail operational amplifier (OA) MCP6V01 as a differential amplifier (DA) [12]. The amplification constant DA is set by resistors R_6-R_9. Capacitors C_1-C_8 act as power supply filters. Capacitors C_{10}-C_{12} together with bridge resistors R_3-R_5 are low-pass filters at the DA input. On the elements $R_{10}C_{13}$ the output low-pass filter of the DA is assembled. The DA output voltage is fed to the analog input PA0 of the 32-bit microcontroller U2 STM32F030R8 which has a built-in 12-bit ADC [13]. The temperature value is output by the microcontroller to the liquid crystal display DE 119-RS-20/7.5 DS1 [14]. The J2 connector is for microcontroller programming. The reset scheme is organized on R_2C_9. The clock frequency of the microcontroller is an 8 MHz internal RC generator. To optimize the measurement using the ADC, a built-in direct memory access (DMA) controller, which at the hardware level is engaged in sending the measured values of the ADC to the array which is organized in RAM [15].

The main obstacle in the measurement is the network voltage with a frequency of 50 Hz. To neutralize the interference from the network voltage, the number of ADC measurements (DMA transmissions) is experimentally selected, which is repeatedly invested in the network voltage period of 20 ms. So, the measurements array contains ADC readings that have the effect of both positive and negative half-waves of the network voltage. For the measured value N_m the meter program uses the arithmetic mean value of the measurement array. Subsequently, the measured value is passed through a cyclic filter moving average of 10 values.

The meter circuit calculation is performed. The supply current of the platinum temperature sensor HM220 is determined taking into account the passport data for the product. The recommended current that supplies the sensor should be 0.3 to 1 mA. To calculate the measuring bridge, taking into account the reduction of self-heating of the sensor, set the current through the sensor 0.5 mA. According to Ohm's law, without taking into account the sensor resistance and the the resistance of the connecting wires, the resistor R_3 (Fig. 2) will be equal to 6.6 kOhm. The closest value from a rating tier E96 is 6.65 kOhm. The current through the sensor in the operating temperature range -50…+600ºC will vary from 490 µA to 474 µA at this value of the resistor R_3. The resistance of the R_5 sets to the platinum sensor HM220 resistance at a temperature of 0ºC-100 Ohms. The output low-pass filter can be calculated using equation (1) [16].

$$f_{co} = \frac{1}{2\pi R_{10} C_{13}} \quad (1)$$

where f_{co} – the cut-off frequency of the low-pass filter, [Hz]; R_{10} – low-pass filter resistor, [Ohm]; C_{13} – low-pass filter capacitor, [F].

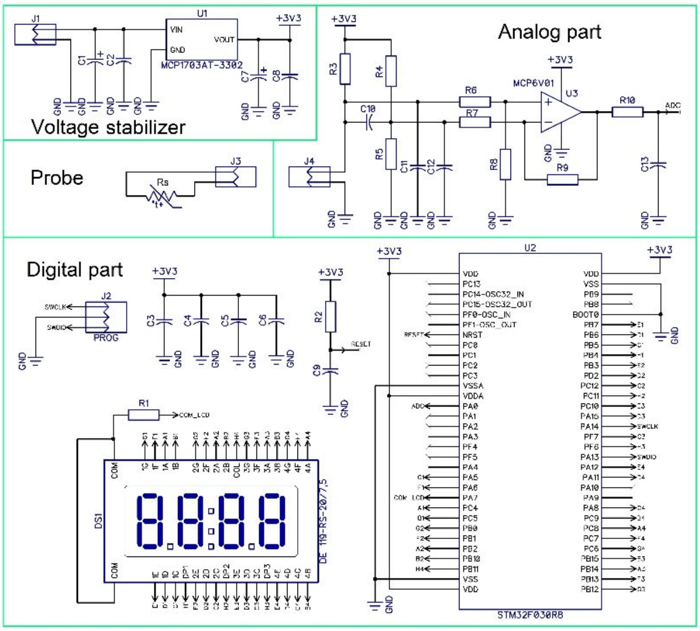

Fig. 2. Electrical schematic diagram of the temperature meter

The cut-off frequency of the low-pass filter will be equal to 3.4 Hz during using resistor R_{10} with a nominal value of 47 kOhm and capacitor C_{13} with a nominal value of 1 μF, which will filter the high-frequency component of the signal at the ADC input.

The circuit operation (Fig. 2) can be described by equation (2) taking into account the assumptions: OA is etalon, the current passing through the resistances R_6-R_7 is absent, the ADC input resistance tends to infinity still provided that the resistance of the connecting wires is zero.

$$U_{ADC} = K_a U_s \left(\frac{R_s}{R_3+R_s} + \frac{R_5}{R_4+R_5}\right) \quad (2)$$

where U_{ADC} – voltage at the ADC input, [V]; U_s – supply voltage circuit (3.3 V), [V]; K_a – DA amplification constant; R_s – temperature sensor resistance, [Ohm]; R_3-R_5 – Wheatstone bridge resistors, [Ohm].

Based on the HM220 sensor, the probe was assembled for the gas temperature meter. Since the selected scheme has no thermal compensation, we use a thermostable wire with a constantan diameter of 0.8 mm as connecting wires. With a probe length of 1 m, the resistance of the connecting wires will be about 2 Ohms. This will lead to the need for software compensation of the meter characteristics from +5ºC at a temperature of -50ºC, to +6.2ºC at a temperature of +600ºC.

Structurally, the meter consists of a probe (Fig. 3) and the measuring unit according to the electric schematic diagram of Figure 2. The probe consists of a rod in which the sensor is fixed, protected from mechanical damage by a corolla on one side and the handle on the other. The rod and corolla is made of stainless steel [17,18]. Heat-resistant constantan conductors are stretched from the sensor in the rod to the handle. The sensor is welded to the constantan conductors [19,20]. The measuring unit is connected to the probe with a 1 m long SHVVP 2x1 copper cable with a connector.

The limit of absolute error, which is expressed for the platinum temperature sensor HM220 is described by formula (3):

$$\Delta t_s = \pm[0.3 + 0.005|t|],\ ^{\circ}C \quad (3)$$

where Δt_s – absolute sensor error, ºC; t – measured temperature, ºC.

The sensor has a normalized characteristic. Nominal values of resistance - temperature for this thermocouple are presented in Table 1.

The output voltage normalization of the DA over the ADC input range is determined by solving the system of equations (4). The system of equations must be solved with respect to the unknown quantities K_a and R_4.

$$\begin{cases} U_{R80.31} = K_a U_S \left(\frac{R_{S80.31}}{R_3+R_{S80.31}} - \frac{R_5}{R_4+R_5}\right) \\ U_{R313.71} = K_a U_S \left(\frac{R_{S313.71}}{R_3+R_{S313.71}} - \frac{R_5}{R_4+R_5}\right) \end{cases} \quad (4)$$

where $U_{R80.31}$ – voltage at the ADC input at temperature -50ºC (sensor resistance 80.31 Ohm) V; $U_{R313.71}$ – voltage at the ADC input at a temperature of +600ºC (sensor resistance 313.71 Ohm) V; K_a – DA amplification constant; $R_{S80.31}$ – the sensor resistance at temperature -50ºC, Ohm; $R_{S313.71}$ – the sensor resistance at temperature +600ºC, Ohm; R_3-R_5 – Wheatstone bridge resistors, Ohm.

Apply to expressions (4) the nominal values of resistors R_1 = 6500 Ohm, R_3= 100 Ohm, supply voltage U_s=3.3 V and the desired value of voltages at a temperature of -50ºC (sensor resistance 80.31 Ohm) $U_{R80.31}$ and +600ºC (sensor resistance 313.71 Ohm) $U_{R313.71}$, which corresponds to the extreme values of the output voltage range of the DA.

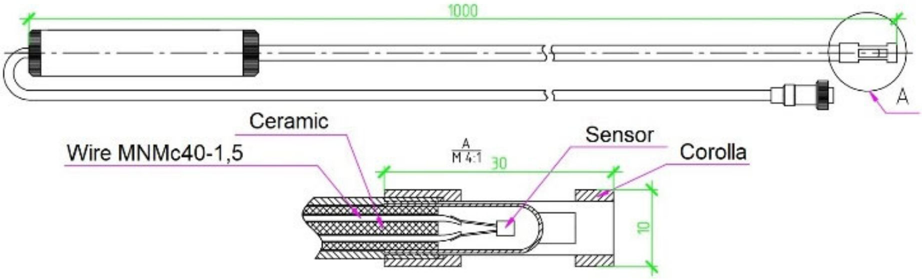

Fig. 3. The design of the probe of the gas temperature meter

Table 1.
Normalized characteristics of the HM220 sensor type "pt100" Heraeus in the range -50...+600 °C

°C	-50	0	50	100	150	200	250	300	350	400	450	500	550	600
Ω	80.31	100.00	119.40	138.51	157.33	175.86	194.10	212.05	229.72	247.09	264.18	280.98	297.49	313.71
Ω/°C	0.397	0.391	0.385	0.379	0.374	0.368	0.362	0.356	0.350	0.345	0.339	0.333	0.327	0.322

The voltages values $U_{R80.31}$ and $U_{R313.71}$ should be selected with a margin for the saturation voltage OA and taking into account that the calculated K_a and R_4 will have to be chosen from a discrete series of denominations and that the probe resistance will increase the ADC input voltage U_{adc}. Taking into account the above, we selected the voltage $U_{R80.31}$ equal to 0.1 V and $U_{R313.71}$ equal to 3.1 V. Apply to data in (4) we obtain a system of equations (5):

$$\begin{cases} 0.1 = K_a\left(0.0394 - \frac{330}{R_4+100}\right) \\ 3.1 = K_a\left(0.1487 - \frac{330}{R_4+100}\right) \end{cases} \quad (5)$$

Solving the system of equations using the SMath Studio program, we obtain K_a equal to 27.45 and R_2 equal to 9129.05 Ohms.

The DA amplification constant is given according to equation (6) where R_6=R_7 and R_8=R_9:

$$K_a = \frac{R_9}{R_7} \quad (6)$$

where K_a – DA amplification constant, R_7, R_9 – resistors that specify the amplification constant, [Ohm].

Taking into account (6) we take R_6 = R_7 = 10 kOhm and accordingly R_8 = R_9 = 274 kOhm from a number of denominations E96. So, the value of K_a will be equal to 27.4, and the closest value of R_4 from a number of denominations will be equal to 9.09 kOhm.

Apply to values of K_a, U_s, R_3, R_4 and R_5 in expression (2) we find the function of resistance converting of the sensor in proportion to the voltage at the input of the ADC.

$$U_{ADC} = \frac{90.72R_s}{R_s+6650} - 0.98 \quad (7)$$

An ideal 12-bit ADC has a conversion function [21]:

$$U_{ADC} = \frac{NU_{ref}}{4095} \quad (8)$$

where U_{ADC} – voltage at the ADC input, V; N – ADC code value; U_{ref} – ADC reference voltage (3.3 V), V.

Apply in (8) to (7) and expressing N, we obtain a theoretical model of the sensor resistance transformation into the value of the N – ADC code (9) for the presented schematic diagram of Figure 2:

$$N = \frac{112203R_s}{R_s+6650} - 1220.92 \quad (9)$$

Figure 4 shows the theoretical and experimental dependences of the ADC code N on the resistance of the sensor.

The theoretical dependence of the ADC code on the resistance is based on formula (9). The experimental dependence is removed on the assembled scheme of Figure 2 using a precision resistance box MSR-60M.

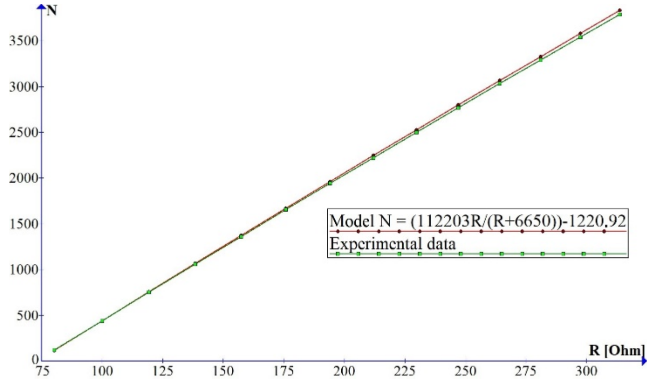

Fig. 4. Theoretical and experimental dependences of the ADC code on the resistance

The experimental dependence of the ADC code on the resistance differs from the theoretical one because the OA, ADC have errors, the resistors used have a tolerance of 1% and the resistance set by the resistance store MSR-60M also has an error that at an ambient temperature of 20±2°C expression (10):

$$\delta = \pm\left[0.02 + 2\cdot 10^{-5}\left(\frac{R_{max}}{R} - 1\right)\right], \% \quad (10)$$

where δ – the relative error of the resistance box, %, R_{max} – the maximum value of the generated resistance (11111.1 Ohm), Ohm; R – nominal value of the included resistance, Ohm.

According to formula (10), the resistance box at a temperature of 20 ±2 ° C has an absolute error in the resistances reproduction of 80.31 Ohm ±18.5 mOhm and 313.71 Ohm ±64.9 mOhm. The absolute error of the resistance box in terms of the generated temperature in the range -50…+600 ºC following expression (10) and Table 1 will look like (11):

$$\Delta t_{rb} = \pm[0.058 + 0.00024|t|], \ ^{\circ}C \quad (11)$$

where Δt_{rb} – the absolute error of the generated temperature of the resistance box MSR-60M, t – generated temperature, °C.

Expression (11) shows the expediency of using the resistance box MSR-60M to adjust the circuit of the meter, because its error is less than five times relative to the error of the sensor HM220 (3).

In general, the resistance of the probe will be (12):

$$R_p = R_s + R_{cw} \quad (12)$$

where R_p – probe resistance, Ohm; R_s – sensor resistance, Ohm; R_{cw} – resistance of connecting wires, Ohm.

The meter will display an increased temperature due to the resistance R_{cw} during connecting the probe to the measuring unit (13).

$$R_{cw} = 2(R_c + R_{SHVVP} + R_t) \quad (13)$$

where R_{cw} – resistance of connecting wires, Ohm; R_c – resistance of a constantan wire, Ohm; R_{SHVVP} – wire resistance SHVVP, Ohm; R_t – transient resistance of the connector, Ohm.

The resistance of the connecting wires of the probe R_{cw} can be measured at one of the reference points 0°C and 100°C.

To measure the probe resistance at the point 0°C it is necessary to install the probe and the high-precision TL-4 №1 thermometer in a metal test tube. Immerse the test tube in a mixture consisting of distilled water and ice formed from this water. Measure the resistance of the probe during the readings of the thermometer TL-4 №1 become 0°C.

To measure the probe resistance at the point 100°C it is necessary to install the probe and the high-precision TL-4 №3 thermometer in a metal test tube. Immerse the test tube in distilled boiling water. Measure the resistance of the probe during the readings of the TL-4 №3 thermometer become 100°C.

To adjust the meter to the actual temperature, it is necessary to determine the difference between the resistance tabular value Table 1 and measured for this temperature. Table 1 adjust by adding resistance R_{cw}.

Connect the resistance box MSR-60M to the probe J4 connector (Fig. 2) and, by dialing the resistance according to the corrected Table 1, remove the dependence of N = f(R) code N ADC on the resistance. The ADC code N in the setting mode is displayed on the DS1 indicator (Fig. 2). With the help of SMath Studio, MathCad, Advanced Grapher and other computer programs according to the results of the dependence N = f(R) (Fig. 4) in accordance with Tab. 1 build up the dependence of temperature on the code N (Fig. 5).

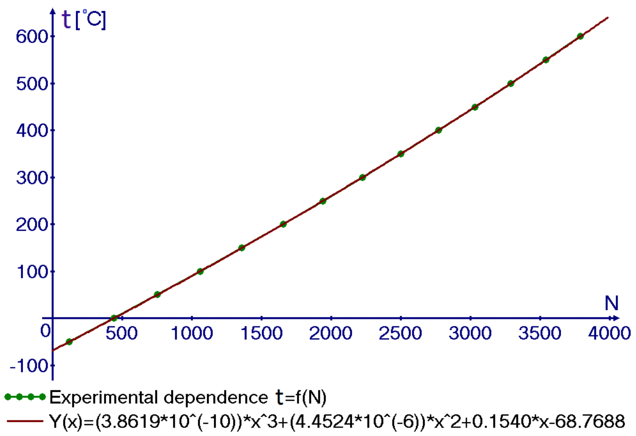

Fig. 5. Dependence of temperature on the ADC code

Figure 5 shows the temperature dependence (set by the resistance by MSR-60M) on the code N and the result of the approximation of the temperature dependence on the code N by a polynomial of the 3rd order.

For the experimental scheme, a third-order polynomial calculated using Advanced Grapher has the form (14):

$$t = 3.8619 \cdot 10^{-10} N_m^3 + 4.4524 \cdot 10^{-6} N_m^2 + \\ +0.1540 N_m - 68.7688 \quad (14)$$

where t – temperature, ºC; N_m – the measured value of the ADC code.

According to GOST 5307-77, the resistance temperature coefficient of the constantan wire MNMc40-1,5 in the temperature range from 20 to 100ºC is from $-2 \cdot 10^{-5}$ to $6 \cdot 10^{-5} K^{-1}$. Which will give the maximum change in resistance at 100ºC 6 mOhm, which in temperature equivalent will be equal to +0.016ºC. To determine the error at temperatures above 100ºC, the dependence of the resistance of the wire MNMc40-1,5 with a diameter of 0.8 mm and a length of 2 m in a linear furnace using a precision multimeter Yokogawa 7555. The absolute error of which at an ambient temperature of 23 ±5ºC and measuring the resistance of a 4-wire circuit in the range up to 200 Ohms, is (15):

$$\Delta R = \pm[0.007 + 0.00019R], Ohm \quad (15)$$

where ΔR – absolute error of resistance measurement by Yokogawa 7555 multimeter, Ohm; R – measured resistance, Ohm.

The maintaining error of the temperature in the furnace is ± 10ºC.

The experimental dependence of the resistance of the wire MNMc40-1,5 with a diameter of 0.8 mm and a length of 2 m on temperature is shown in Figure 6.

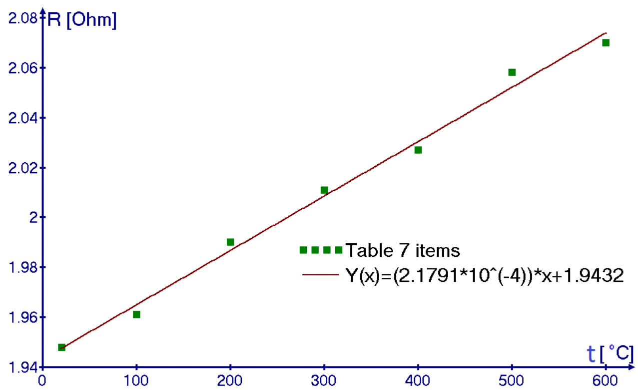

Fig. 6. The resistance dependence of the wire MNMc40-1,5 on temperature

Figure 6 shows the experimental and approximate by the method of least squares data on the dependence of the resistance of the wire MNMc40-1,5 on temperature. The maximum change in the wire MNMc40-1,5 resistance with a diameter of 0.8 mm and a length of 2 m at a temperature of 600ºC is 122 mOhm relative to the resistance at a temperature of 19ºC, which in temperature equivalent will be equal to 0.379ºC.

The SHVVP 2x1 copper connecting wire and the measuring unit work in the temperature range -20…+40ºC. The rated value of the resistance of 1 km of SHVVP 2x1 wire at a temperature of 20ºC is not more than 19.5 Ohms, the measured value of the resistance of 2 m of wire with a Yokogawa 7555 multimeter at a temperature of 20ºC is 40 mOhms. According to [22], the temperature resistance of copper is equal to $3 \cdot 10^{-3}$ K^{-1}. It will give the maximum change in the resistance of the connecting wire SHVVP 2x1 in the temperature range -20…+40ºC relative to the temperature of 20 ºC -4.8 mOhms, which in temperature equivalent will be equal to 0.015ºC.

DS1110-01 (Connfly electronic) is used as a connector, the maximum rated transient resistance of the contacts and the insulation resistance of which is 100 mOhms and 1 GOhm, respectively [23]. Experimental studies of transient resistance have shown that they are inflated by the manufacturer. In Figure 7 shows the transient resistance measurements of the ten four-pin DS1110-01 connectors using a Yokogawa 7555 multimeter. The maximum measured value of the transient contact resistance is 15 mOhms, 90% of the measured values are in the range of 8±4 mOhms.

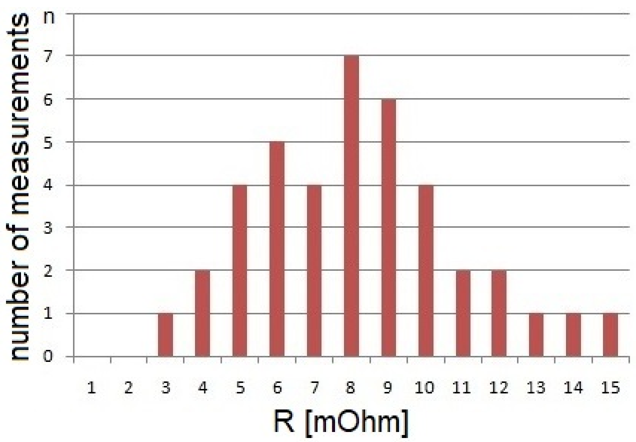

Fig. 7. Transient contact resistance of DS1110-01 connectors

To reduce the transient resistance, it is recommended to connect the contacts of the DS1110-01 connector in parallel, so that the transient resistance will be halved.

The temperature measurement error of the meter can be estimated from expression (16):

$$U = \sqrt{U_c^2 + U_D^2 + U_S^2 + U_{Const}^2 + U_{\mathrm{SHVVP}}^2} \quad (16)$$

where U – total standard uncertainty for type B, U_c – the uncertainty is due to the meter circuit error, U_D – the uncertainty is due to the to the meter discreteness, U_S – uncertainty is due to sensor error, U_{Const} – the uncertainty is due to the error from the change in resistance of the constantan wire, U_{SHVVP} – the uncertainty is due to the error from the change in resistance of the wire SHVVP 2x1.

The uncertainty due to the meter circuit error U_c is 0.07°C during using the resistance box MSR60-M as a circuit calibrator [9,24].

Uncertainty due to the meter discreteness U_D, at a resolution of the gas temperature meter 1°C (17):

$$U_D = \frac{1}{2\sqrt{3}} = 0.289 \ ^\circ C \quad (17)$$

Uncertainty due to temperature sensor error U_S for maximum temperature +600°C (18):

$$U_S = \frac{3.3}{\sqrt{3}} = 1.905 \ ^\circ C \quad (18)$$

Uncertainty due to error from the change in resistance of the constantan wire U_{Const} for a maximum temperature of +600°C (19):

$$U_{\mathrm{Const}} = \frac{0.379}{\sqrt{3}} = 0.219 \ ^\circ C \quad (19)$$

Uncertainty due to error from change in resistance of SHVVP 2x1 wire U_{SHVVP} (20):

$$U_{\mathrm{SHVVP}} = \frac{0.015}{\sqrt{3}} = 0.009 \ ^\circ C \quad (20)$$

The total standard uncertainty determined by type B by expression (16) for maximum values is 1.94ºC. The largest contribution to the total standard uncertainty is given by the error of the sensor "pt100", so the error increases in proportion to the value of the measured temperature.

3. Results and discussion

As a result of the analysis of theoretical and practical studies related to the increase of air pollution by flue gas emissions, it became necessary to develop a design of gas temperature meter in the range -50…+600ºC for environmental control of emissions.

The following types of sensors are the basis of temperature meter designs used today in the environmental sphere: semiconductor, non-contact (pyrometric), thermocouples, and resistance thermometers. Meters on semiconductor sensors do not work at temperatures above 150ºC. Pyrometric meters do not allow to measure the temperature of the environment, but only the surface temperature. Thermocouple-based meters have such disadvantages as a weak signal, nonlinearity, and the need to use a compensating element of the cold joint.

We have developed a digital portable gas temperature meter in the range of -50…+600ºC based on a thin film resistance thermometer type "pt100" for measuring the temperature of dust and gas flows in sources of air pollution. During the experimental research and analysis of the temperature error of the meter made by the proposed method, it was found that the error mainly depends on the error of the sensor "pt100". Based on the proposed design of the temperature meter using thermostable conductors, with the advent of appropriate sensors, in the future it is possible to develop designs of temperature meters with an extended measuring range and less error. Thus, the presented design of the gas temperature meter allows measurements in aggressive environments in ecological studies of emissions of combustion products and is the most appropriate.

4. Conclusions

As a result of this work, a digital portable gas temperature meter in the range -50…+600ºC was developed to measure the temperature of dust and gas flows from atmospheric pollution sources, with the price of the lowest digit of the reading device 1ºC.

Thanks to the developed design of the measuring unit, probe, and software, a high-precision temperature meter has been designed based on the pt100 sensor, which is easy to manufacture, easy to use, and maintain. The proposed design allows you to make probes of different lengths.

Analysis of the temperature error of the manufactured meter revealed that the total standard uncertainty calculated for the maximum temperature value of the measuring range is 1.94ºC.

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