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Methodology for Determining the Response Time of Thermo Transducers for Measuring the Temperature of Gas Flows

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Abstract

Gas flow temperature is an important parameter of the process, determines the quantitative and qualitative indicators of the original product, the presence of defects, the state of technological equipment, as well as the safety of the process. Therefore, its measurement must be carried out continuously, with high accuracy, low inertia and high reliability, since the information signal about the value of temperature is used in information-measuring systems and automatic control and regulation systems. When measuring a time-varying gas flow temperature, the thermo transducer does not have time to keep track of the temperature change since it takes some time to change the temperature of its sensitive element. Distortion of thermo transducer due to the non-stationarity of thermal processes both in the thermo transducer itself and between it and the environment is due to its inertial properties (thermal reaction). Due to these properties, there is an additional difference between the temperature of the sensing element and the temperature of the gas flow, which determines the dynamic error in measuring the flow temperature. The method of determination of inertial properties of thermo transducer for different gas flow velocities by the measured value at one basic flow velocity is proposed in the article.

Keywords: methodology; gas flow; measurements; temperature; time of thermal reaction.

1. Introduction

The specifics of the conditions for measuring the temperature of gas flows is determined by the variety of technological objects used in industrial production, physicochemical properties and flow velocity, the range of measured temperatures, the requirements for the accuracy and reliability of the measurement results, the nature of the flow and the likely perturbations of technological processes. Thermo transducers designed to measure the temperature of gas streams have certain features both in technical and metrological characteristics and in design principles [1].

The quantitative indicator of the inertial properties is the thermal response time, which according to [2] is defined as the time required to change the measurements of the device by a certain percentage of complete change at a step change in the temperature of the medium.

The method of determining the time of thermal reaction, which is set in [2] and is meant for common industrial thermo transducer, cannot be applied to such thermo transducer. According to this method, the determination of the time of thermal reaction is carried out by cooling or heating the thermo transducer in intensively mixed water, i.e. at a very large value of the coefficient of convective heat transfer. For gas flows, the values are insignificant, although they increase with increase in speed, but do not reach large values [3]. Therefore, the value of the thermal reaction time, determined by the standard method, cannot be judged on the inertial properties of thermo transducer, designed to measure the temperature of the gas stream.

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2. Analysis of publications and research

Analytical dependencies for determining the time of thermal reaction of thermo transducer are derived on the basis of the theory of regular thermal regime [4]. Studies of the influence of various factors on the time of thermal response time have been carried out in fundamental works [5]-[7]. Such studies were also conducted by the author [8]. Thermal reaction time determination studies have been conducted by some authors only for specific operating conditions of the thermo transducer, but no comprehensive studies on the determination of the generalized dependence for the thermal response time over a wide range of velocity changes have been performed.

3. The purpose of the study

Thermo transducers can be operated over a wide range of gas flow velocities, and determining the dependence of the change in thermal reaction time on the rate of flow change poses some difficulties. Therefore, the task is to find a general analytical dependence by which it is possible to calculate the value of time of thermal reaction at any velocity V at its known value in the stream of calm air (in natural convection conditions), which is easy to realize in laboratory or production conditions.

4. Experimental studies

Let us consider the results of experimental studies of the change in the thermal reaction time of a group of thermo transducers commercially produced by the industry for measuring the temperature of various gas streams with a braking chamber. Such thermo transducers allow measurement of flow temperatures in the speed range from 20 to 600 m/s and temperatures up to 1800 °C. Such measurements were most widespread in the range of speeds up to 300 m/s.

Experimental studies to determine the time of thermal reaction were performed on thermo transducer Pt-5680. It is intended for measuring the exhaust gas temperature of internal combustion engines, as well as the temperature of air braking in wind tunnels [9]. A design feature of the thermo transducer is the presence of a braking chamber, which is designed to artificially slow the flow rate at the location where the sensitive element is located. Such thermo transducers are characterized by a high and stable recovery coefficient over a wide range of gas flow rate changes. The higher and more stable the recovery factor, the better the quality of the thermo transducer. The general view is shown in Fig.1.

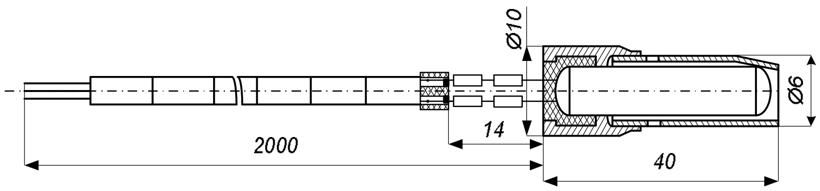

Fig.1. General view of the Pt-5680 thermo transducer.

The thermo transducer can be operated in the range of flow rates from 20 to 300 m/s and pressure from 30 to 600 kPa. A sensitive element is a platinum thermal resistor with a nominal static characteristic of Pt10 according to [2], [10], which is placed in a 6x0.5 mm stainless steel tubular housing. The braking chamber is made in the form of two holes with a diameter of 3 mm, placed behind the sensing element, which provides heat exchange between the gas flow and the sensing element of thermo transducer. The ratio of the areas of the outlets of the braking chamber to the inlet is 0.125 and selected from the calculation of braking gas flow. Measuring range is from -50 to 650 °C. The permissible value of the main error does not exceed ±1 °C in the range from minus 50 to 100 °C, ±2 °C in the range from 100 to 350 °C and ±3 °C in the range from 350 to 650 °C. The thermal response time is not more than 15 s in the stream of calm air. The recovery factor for Mach numbers in the braking chamber from 0.2 to 0.6 ranges from 0.96 to 0.97. Mounting the thermo transducer to the housing of the measuring probe is ensured by welding.

Since the time of thermal response time in the technical documentation for thermo transducer is normalized in the flow of calm air (in the conditions of natural convection), experimental studies were conducted to determine this indicator in the range of speed changes from 0 to 300 m/s. On the basis of these studies, it is proposed to determine the analytical dependence of the change in thermal reaction time for different velocities of the gas stream by the measured value in the stream of calm air.

The experimental studies were carried out in an aerodynamic pipe in an open air working part with a subsonic nozzle, which provided a change in the flow velocity in the range from 0 to 300 m/s. The thermo transducers were preliminary installed in the oven, where it was heated to a temperature of 70 °C and transferred to a stream of air with a constant temperature. The transient process of cooling the thermo transducer was recorded using a high-speed secondary device. The scheme of the measuring unit for determining the time of thermal reaction is shown in Fig.2.

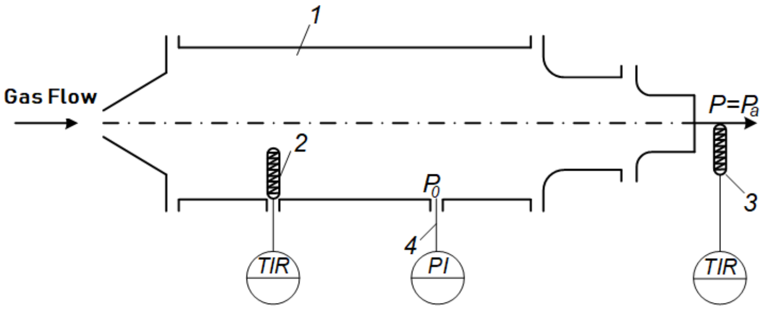

Fig.2. Scheme of the measuring unit for determining the time of thermal reaction: 1 - wind tunnel with open working part; 2 - platinum resistance thermocouples for measuring the temperature in the wind tunnel; 3 - investigated thermo transducer; 4 - pressure gauge for measuring full pressure

Pre-programmed test thermo transducer 3 was installed along the axis of the nozzle at a distance of 40… 50 mm from its cut. For these conditions, the static pressure is practically consistent with the atmospheric pressure, which makes it easier to determine the flow velocity at the location of the thermo transducer. The flow temperature in the wind tunnel was measured using a pre-programmed platinum resistance thermocouple 2.

The gas flow velocity was determined by the static pressure at the installation site and the total pressure, which was determined by the full pressure gauge 4 installed in the wind tunnel. The velocity was changed every 20 m/s. The transient curves obtained for the five thermo transducer s determine the average values of thermal inertia time, which are shown in the table.

Table 1. Dependence of thermal reaction time on gas flow velocity

V, m/s	0	20	40	60	80	100	120	140
ε, s	13.2	10.1	8.22	7.07	6.08	5.37	4.73	4.42
V, m/s	160	180	200	220	240	260	280	300
ε, s	4.02	3.57	3.36	3.09	2.85	2.62	2.53	2.49

The experimental data were processed using Curve Expert1.3, which performs operations on the experimental data arrays. It has a large number of regression analysis (linear and nonlinear) models, as well as various interpolation schemes, presenting experimental data in the most accurate and convenient way.

The obtained transient curves determined the dependence (Fig.3), which was approximated by a polynomial $\varepsilon_V = a + b \cdot V + c \cdot V^2$ with the following coefficients: a = 11.73924; b = -0.07536; c = 0.0001547619. The correlation coefficient r between experimental results and the calculated polynomial values is r = 0.982, which is sufficient for engineering calculations.

Thus, a comparison of the values of the thermal reaction time over the entire velocity range from 0 to 300 m/s, determined experimentally and calculated by the proposed polynomial show that the correlation coefficient between the results is in the range of 0.982 to 0.985. That is, the reliability of the proposed polynomial for the calculation of the time of thermal reaction in a wide range of velocity changes in the flows of calm air is confirmed.

To determine the time of thermal reaction under real operating conditions without the possibility of dismantling the thermo transducer from the process object, to obtain a cooling transition curve, it is necessary to immediately heat it to a temperature of 20-40 °C above the operating temperature of operation. This can be achieved by applying a voltage pulse of short duration (up to 10 s) and large value to the thermo transducer. Then connect the thermo transducer to a high-speed secondary device, record the cooling process, and calculate the thermal inertia time value according to the above method. The research results show that the correlation coefficient between the experimental and calculated values of the thermal reaction time is within not less than 0.980 – 0.985.

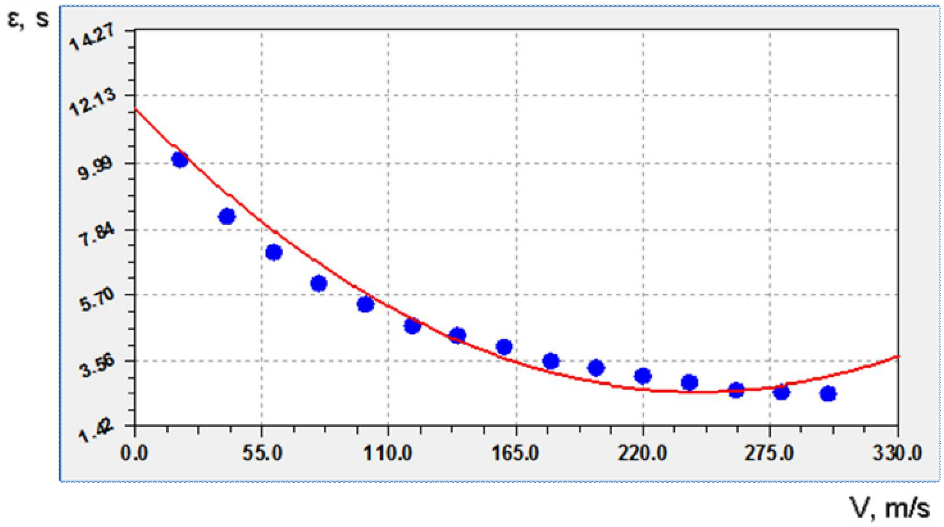

Fig.3. Experimental (●) and polynomial calculated (─) thermal response time depending on gas flow velocity.

5. Conclusion

The article describes the method for determining the thermal response time for thermo transducer, designed to measure the temperature of the gas stream.

The materials of the article are of practical importance because they allow researchers to determine the time of thermal reaction of thermo transducers at a wide range of speeds by the measured value in a stream of calm air, which is easy to implement in laboratory or production conditions. The technique of determining the time of thermal reaction under real conditions of operation of thermo transducer without removing it from the technological object is also offered.

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Методика визначення часу термічної реакції термоперетворювачів для вимірювання температури газових потоків

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Анотація

Температура газових потоків є важливим параметром технологічного процесу, визначає кількісні і якісні показники вихідного продукту, наявність браку, стан технологічного обладнання, а також безпеку функціонування процесу. Тому вимірювання її необхідно проводити неперервно, з високою точністю, невеликою інерційністю і високою надійністю, оскільки інформативний сигнал про значення температури використовується в інформаційно-вимірювальних системах та автоматичних системах контролю та регулювання. При вимірюванні змінної в часі температури газового потоку термоперетворювач (ТП) не встигає слідкувати за зміною температури, оскільки для зміни температури його чутливого елемента потрібен деякий час. Спотворення показів ТП через нестаціонарності теплових процесів як в самому ТП, так і між ним і навколишнім середовищем обумовлені його інерційними властивостями (термічною реакцією). За рахунок цих властивостей виникає додаткова різниця між температурою чутливого елемента і температурою газового потоку, яка визначає динамічну похибку вимірювання температури потоку. В статті запропонована методика визначення інерційних властивостей ТП для різних швидкостей газового потоку за виміряним значенням при одній базовій швидкості потоку.

Ключові слова: методика; газовий потік; вимірювання; температура; час термічної реакції.