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IMPROVING THE ACCURACY OF TEMPERATURE MEASUREMENTS IN HEAT SUPPLY SYSTEMS

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ABSTRACT

The constant rise in energy prices leads to an increase in the cost of thermal energy, which is used in heat supply systems for industrial and residential premises. Therefore, improving the accuracy of measuring the heat supplied to consumers is an urgent task. Instrumental metering of heat energy requires regular measurement of the temperature of the coolant in the pipelines of the heat supply system. There is an opinion that all the problems of measuring temperature when accounting for thermal energy have been solved. However, this is not the case. The analysis shows that the systematic component of the error in measuring the temperature and the temperature difference between the supply and return pipelines, especially in conditions of small values of the difference, makes a significant contribution to the instrumental error of accounting for thermal energy. The article discusses solutions to minimize these errors in temperature measurement, taking into account the consumption of thermal energy.

KEYWORDS

Temperature measurements;
Measurement error;
Thermal energy;
Thermodynamics;
Metrology.

Introduction

Global heat transfer processes are not limited to heating the Earth by solar radiation. Massive convection currents in the atmosphere determine the daily changes in weather conditions around the globe. Temperature changes in the atmosphere between the equatorial and polar regions, together with the Coriolis forces due to the rotation of the Earth, lead to the appearance of continuously changing convection currents such as trade winds, jet streams, and warm and cold fronts. The transfer of heat (due to thermal conductivity) from the molten core of the Earth to its surface leads to volcanic eruptions and the appearance of geysers. In some regions, geothermal energy is used to heat premises and generate electricity. Thermal energy is an indispensable participant in almost all production processes. We will mention the most important of them, such as smelting and processing metals, engine operation, food production, chemical synthesis, oil refining, and the manufacture of a variety of items - from bricks and dishes to cars and electronic devices. Many industrial production and transport, as well as thermal power plants, could not operate without heat engines - devices that convert heat into useful work. Examples of such machines include compressors, turbines, steam, gasoline and jet engines. One of the most famous heat engines is the steam turbine, which implements part of the Rankine cycle used in modern power plants. The working fluid - water - is converted into superheated steam in a steam boiler heated by burning fossil fuels (coal, oil or natural gas) in the here. High pressure steam rotates the shaft of a steam turbine, which drives a generator to generate electricity. Waste steam is condensed when cooled by running water, which absorbs some of the heat not used in the Rankine cycle. Further, water is supplied to a cooling tower (cooling tower), from where part of the heat is released into the atmosphere. The condensate is returned to the steam boiler by means of a pump, and the whole cycle is repeated. All processes in the Rankine cycle illustrate the principles of thermodynamics described above. In particular, according to the second principle, part of the energy consumed by the power plant should be dissipated in the environment in the form of heat. It turns out that approximately 68% of the energy originally contained in fossil fuels is lost in this way. A noticeable increase in the efficiency of the power plant could be achieved only by increasing the temperature of the steam

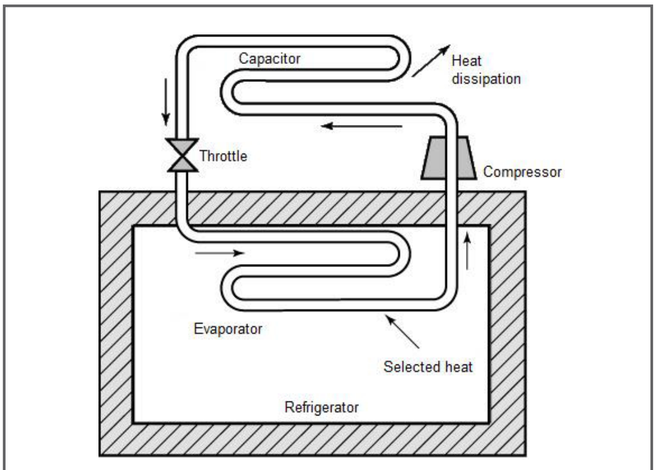

Fig.1. Refrigeration cycle diagram

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boiler (which is limited by the heat resistance of the materials) or by lowering the temperature of the environment where the heat goes, i.e. atmosphere. Another thermodynamic cycle that is of great importance in our daily life is the Rankine steam compressor refrigeration cycle, the diagram of which is shown in the figure 1.

In refrigerators and domestic air conditioners, energy is supplied from the outside to provide it. The compressor raises the temperature and pressure of the working substance of the refrigerator - freon, ammonia or carbon dioxide. The superheated gas is fed to the condenser, where it is cooled and condensed, giving off heat to the environment. The liquid leaving the condenser pipes passes through the throttling valve into the evaporator, and part of it evaporates, which is accompanied by a sharp drop in temperature. The evaporator removes heat from the refrigerator chamber, which heats the working fluid in the pipes; this liquid is supplied by the compressor to the condenser and the cycle is repeated again.

All this suggests that thermal energy is an integral part of our lives. For this reason, taking into account the consumption of thermal energy, there is a need to minimize errors in temperature measurement and increase accuracy.

We know that thermal (thermodynamic) equilibrium is a state of a body or a system of bodies in which its thermodynamic parameters (*p*, *V*, *m*, etc.) remain unchanged for an arbitrarily long time. Temperature is a characteristic of the internal state of a macroscopic system - a state of thermal equilibrium. Temperature is a thermodynamic parameter that is the same in all parts of a thermodynamic system in thermal equilibrium. The temperatures of bodies in thermal contact are leveled.

In heat meters, the calculation of heat and mass of the coolant with a given accuracy in most cases is performed according to the formulas [1].

$$G = \int_{t_1}^{t_2} Q_0 k\left(T_1 - T_2\right) dt$$

$$M = \int_{t_1}^{t_2} Q_0 dt$$

Where:

Q_0 - volumetric flow rate; T_1 and T_2 - temperature values of the heating agent in the supply and return pipelines; ρ - coolant density; k - thermal coefficient (Stuck coefficient), which depends on the parameters of the heat carrier and the place of installation of the flow meter - on the pipe of direct or reverse water supply.

Platinum resistance thermometers (RT) are widely used as temperature meters in heat meters, the permissible error of temperature conversion for the best accuracy class of which is standardized according to GOST by the expression $\Delta_D = \pm (0.15 + 0.002\ |T|)$. With a temperature difference of $\Delta T \approx 10$ °C and the temperature of the coolant in the supply pipeline $T_1 \approx 80$ °C, the permissible component of the error in measuring the temperature difference can reach ±0.5 °C, which is equivalent to an error in measuring heat of ±5% in a closed heat supply system.

At the same time, the contribution of the component by measuring the flow rate of the coolant in modern heat meters does not exceed ±1%. Thus, the contribution of the "complex" type of measurements - flow measurements - is 5 times less than the contribution of "simple" temperature measurements.

The existing domestic heat consumption systems are characterized by a very low utilization of the thermal potential (a small temperature difference between the supply and return pipelines) even in conditions of normal heat supply. If we also take into account the currently widely practiced abnormal heat supply due to the high cost and shortage of energy resources, the situation becomes generally sad.

Increasing the accuracy of measuring the heat energy supplied to the consumer directly depends on the accuracy of measuring the temperature of the coolant, or rather, the accuracy of measuring the temperature difference between the supply and return pipelines. Recently, to reduce the error in measuring the temperature difference, a matched and matched pair of platinum thermistors is used that is use sets of resistance thermometers. This, of course, improves the situation, but does not radically change it, since only the error component generated by the set of thermistors is compensated for, without taking into account the contribution of other elements of the thermometer (for example, the measuring channel). The methods used to reduce the components of the instrumental error of resistance thermometers can mainly be attributed to the conservative methods of stabilizing its static transformation characteristics.

An exception can be considered the stabilization of the conversion characteristics of the measuring channel of the TS due to the introduction of deep negative feedback - this is one of the structural methods for increasing the accuracy of temperature measurement. The use of structural-algorithmic methods of error correction is advisable when the possibilities of conservative methods have been exhausted [2]. In the presence of additive and multiplicative components of the error, the equation of the measuring instrument (SI), which has a linear transformation characteristic, has the form:

$$y = K\left[1 + \delta_M(t)\right]x + \Delta_y(t) = K\left[1 + \delta_м(t) + \delta_a(t)\right]x$$

Where:

K - SI conversion factor; $\delta_м(t)$ - total relative multiplicative error; $\Delta_y(t)$ - total absolute additive error at the SI output; $\delta_a(t) = \Delta_y(t)/(K \cdot x)$ - relative additive error reduced to the SI input; x - input measured value; y - output signal (value) SI.

In the measuring channel of the resistance thermometer, both components of the error take place - additive and multiplicative (Δ_y and $\delta_м$) due to the zero offset of the measuring amplifier and a change in its transmission coefficient under the influence of external destabilizing factors. Algorithms for compensating the additive and multiplicative components of the error of the measuring channel of the SI by using structural algorithmic methods are considered in [3]. A specific implementation of the structural-algorithmic method for increasing the accuracy of the measuring channel of a resistance thermometer by correcting the additive and multiplicative components of the error was proposed in [4].

The figure shows a functional diagram of a device that corrects the additive and multiplicative components of the errors of the measuring channels of two resistance thermometers to reduce the error in measuring the temperature difference $\Delta T = T_1 - T_2$.

On the basis of two common bridge arms (R_1, R_2), a measuring bridge (R_1, R_2, R_3, R_{t1}) is formed, which provides temperature measurements T_1 in the supply pipeline, and a bridge (R_1, R_2, R_{30}, R_{t0}), which forms an exemplary effect (equivalent to an exemplary temperature T_0). To compensate for the error from the instability of the supply voltage, they are both connected to a common power source (parametric voltage regulator R_4, VD) through switch Π_4.

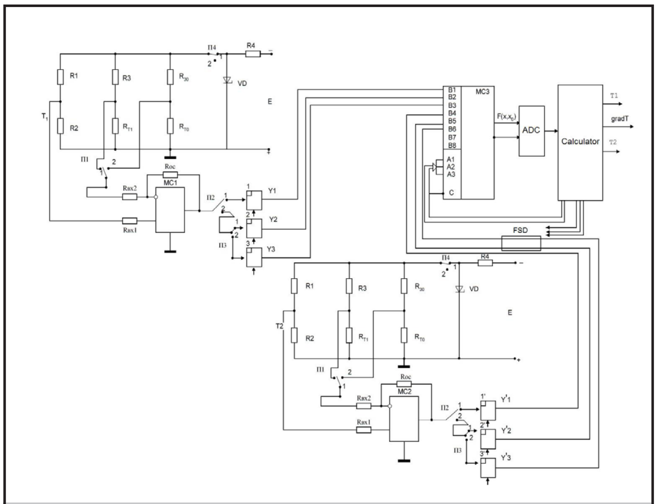

Fig.2. Functional diagram

The second measuring channel for measuring the temperature T_2 in the return pipeline is built in a similar way. The T_2 and T_1 values are used to determine the temperature difference $\Delta T = T_1 - T_2$ in the calculator of the device.

In the measuring channels, the output signals from the measuring and reference bridges are amplified by differential amplifiers MS1 (MS2), made on a type 140UD17 OUPT. The non-inverting input of the amplifier is connected through R_{in1} to the common arms of the bridge (R_1, R_2), and the inverting input with a resistor R_{in2} through switch Π_1 is connected in position 1 to the measuring one, and in position 2 to the exemplary bridges. The feedback resistor R_{oc} determines the required gain. The output signal of the amplifier through switches Π_2 and Π_3 is connected to three memory elements (1, 2, 3) for each of the channels, which are, for example, sample-and-hold circuits. The outputs of these circuits through the MC3 multiplexer are alternately switched to the ADC input.

Conclusion

The use of the structural-algorithmic method to compensate for the zero offset and change the gain of the temperature measuring channel made it possible to reduce the error in measuring the temperature difference by 150 %. This proposal can solve several problems in heat measurements. When using this method in heat meters, the accuracy of measuring the amount of heat is also increased, which provides significant savings in material and financial resources.

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Повышение точности измерения температуры в системах теплоснабжения

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Реферат

Одним из важнейших вопросов термодинамики и систем теплоснабжения сегодня является повышение точности приборов для измерения температуры. Повышение точности измерения температуры в системах теплоснабжения - один из важнейших способов предотвратить расход материалов. В этом направлении проведено достаточно исследований и высказаны различные предложения. В некоторых исследованиях даже отмечалось, что все возможные систематические ошибки в этом направлении были предотвращены. В нашем исследовании было обнаружено, что влияние окружающей среды, температуры в точке входа и выхода из скважины, а также неопределенность измерения термодинамической температуры могут существенно повлиять на результат этого измерения. В данной статье предлагаются решения, позволяющие минимизировать погрешности измерения температуры в различных системах теплоснабжения и измерения.

Ключевые слова: измерение температуры; погрешность измерения; тепловая энергия; термодинамика; метрология.

İstilik təchizatı sistemlərində temperatur ölçmələrinin dəqiqliyinin artırılması

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Xülasə

Hal-hazırki dövrdə termodinamikada və istilik təchizatı sistemlərində ən vacib məsələlərdən biri də temperatur ölçmə vasitələrinin ölçmə dəqiqliyinin artırılmasıdır. İstilik təchizatı sistemlərində temperatur ölçmələrinin dəqiqliyinin artırılması maddiyyat sərfinin qarşısını almağa kömək edən ən əhəmiyyətli üsullardan biridir. Daha əvvəl bu istiqamətdə yetəri qədər tədqiqatlar aparılmış və müxtəlif təkliflər verilmişdir. Hətta bəzi tədqiqat işlərində bu istiqamətdə yarana biləcək bütün sistematik xətalarının qarşısının alındığı da qeyd edilmişdir. Bizim apardığımız tədqiqat işində müəyyənləşdirildi ki, temodinamik temperatur ölçülməsi zamanı ətraf mühitin təsiri, börunun giriş-çıxış nöqtəsindəki temperaturu və qeyri-müəyyənlik bu ölçmə nəticəsinə əhəmiyyətli şəkildə təsir göstərə bilir. Hal-hazırki məqalədə müxtəlif istilik təchizatı və ölçmə sistemlərində temperaturun ölçülməsi zamanı yaranan xətaları minimuma endirmək üçün həllər təklif edilir.

Açar sözlər: temperaturun ölçülməsi; ölçmə xətası; istilik enerjisi; termodinamika; metrologiya.