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One of the parameters which determine the quality of manufactured rolled metal is the temperature to which the metal bars are heated in the furnaces. This parameter is monitored during the continuous measurement of the temperature in the furnace, mainly, using platinum-rhodium temperature measuring transducers – thermocouples in ceramic jackets.

The lifetime of such a thermocouple is determined by the following measurement conditions in the furnace: the range of variation of the temperature is 300–1380°C, the gaseous medium is oxidizing-reducing, the pressure is close to atmospheric, and the rate of flow of the combustion products is low and amounts to 1–10 m/sec. All these parameters are constant or vary slowly with time. The error in determining the temperature should not exceed 0.5% of the measured value.

The operating life of a thermocouple (about 1000 h at present) is limited by the following factors: the presence of free carbon in the gaseous medium leads to the thermoelectrode becoming filled with carbon and, as a consequence, to an inadmissible change in its thermoelectrode characteristics and brittleness, and the considerable temperature gradients along the length of the sensor in the furnace cause it to fracture when the sensor is placed in the well.

The most pressing problem is to produce instruments for measuring this temperature range which do not contain precious materials and which enable measurements to be made over long periods in technological processes.

The most promising methods of measuring high temperatures in furnaces are indirect methods, in which the measured values of the temperature (and other parameters of the sensor) enable one to calculate (establish) the required temperature using the measurement equation of the method. These methods are based on reducing the measured temperature to levels which enable the temperature measurement transducers to operate over a long period [1]. In sensors which make use of these methods, the construction and the transducers are cooled in order to reduce the temperature.

The reduction radiation sensor described here employs an indirect method of measuring the temperature, the basis of which is the thermal balance equation of a thermocouple cooled by a flow of air. The radiation sensor (see Fig. 1) is a tube, on the axis of which two temperature measuring transducers are placed: the working transducer, which is outside the tube, and a control transducer, which is inside the tube. Air is fed to the tube, which cools the transducers and protects them from contact with the gaseous medium of the furnace. The air flows into the furnace. The sensitive element (the junction) of the working transducer is placed at the core of the air jet flowing away from the sensor, which prevents any free carbon and any dust and soot which falls off the working transducer from affecting it, while the temperature at the core of the jet is maintained constant [2] and is measured by the control transducer. The sensitive element of the working transducer senses the radiation heat flux from the burners, the walls of the furnace and the metal in the furnace. Water cooling can be used to cool the body of the reduction radiation sensor.


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The temperature distribution $T(x)$ along the length of the working transducer, assuming that the heat exchange is steady and that there is no temperature gradient over the transverse cross section of the temperature measuring transducers, is described by the equation \[3\]

$$
\frac{d^2 T}{dx^2} + \frac{\alpha S}{\lambda} \left( T_a - T(x) \right) + \frac{\sigma e P \left( \varphi_1 (T_a^4 - T^4(x)) + \varphi_2 (T_n^4 - T^4(x)) \right)}{\lambda} = 0,
$$

where $\lambda$ is the thermal conductivity of the material of the transducer, $W/(m\cdot K)$, $S$ is the equivalent cross sectional area of the transducer, $m^2$, $\alpha$ is the heat-transfer coefficient of the transducer, $W/(m^2\cdot K)$, $T_a$ is the temperature of the air which cools the working transducer, $K$, $T_n$ is the temperature of the furnace, $K$, $P$ is the perimeter of the transverse cross section of the transducer, $m^2$, $\sigma$ is the Stefan–Boltzmann constant ($5.7 \times 10^{-8} W/(m^2\cdot K^4)$), $e$ is the degree of blackness of the sensitive element of the transducer, $\varphi_1$ is the angular irradiance coefficient of the sensitive element of the working transducer by the cold tube of the sensor, and $\varphi_2$ is the angular irradiance coefficient of the sensitive element of the working transducer by the radiating volume of the furnace.

The relation between $\varphi_1$ and $\varphi_2$ and the geometrical parameters of the sensor has the form

$$
\varphi_1(x) = 0.5 - \frac{H(x)}{\sqrt{4H^2(x)} + 1},
$$

where $H(x) = (h - x)/D$ and

$$
\varphi_2(x) = 1 - \varphi_1(x).
$$

Here $x$ is the coordinate along the temperature measuring transducer in the direction from the sensitive element to the external housing of the sensor, $m$, $h$ is the distance from the sensitive element to the section of the external housing of the sensor tube, $m$, and $D$ is the sensor tube diameter, $m$.

The solution of Eq. (1) for $x = 0$ is the heat-balance equation, which describes the relation between the measured temperature in the furnace $T_n$ and the temperatures of the sensitive elements $T$ of the working transducer and $T_a$ of the control transducer.

Assuming that there is no heat flow along the temperature measuring transducers, Eq. (1) becomes

$$
\alpha P \left( T_a - T(x) \right) + \sigma e P \left( \varphi_1 (T_a^4 - T^4(x)) + \varphi_2 (T_n^4 - T^4(x)) \right) = 0.
$$

If the sensitive element of the working transducer is at a distance from the external housing of the sensor where $\varphi_1 = 0$, Eq. (2) simplifies to

$$
\alpha (T_a - T) + \sigma e (T_n^4 - T^4) = 0
$$

and we obtain an explicit expression for $T_a$ – the measurement equation for the reduction radiation sensor method.