FILM THERMOCOUPLE WITH A NICKEL ELECTRODE
FOR MEASURING SURFACE TEMPERATURES

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Surface temperatures are measured by means of contact thermal detectors mainly consisting of thermocouples with wire electrodes. Contact meters disturb the temperature field of the tested object. Distortions are also contributed under transient conditions by the thermal inertia of meters. Therefore, the measured temperature differs from the true surface temperature.

A film thermocouple has been developed for measuring temperature fields of components' surfaces subjected to transient flows of combustion products at 0-1000°C. The surface of the component 1, which is made of a conducting material, was coated with the insulating layers 2 (Fig. 1), consisting of narrow thin strips extending from the temperature measuring point to the thermocouple lead-out conductors. The film electrodes 3 were placed over the insulating layers. The thermocouple junction 4 consists of the contact between the film electrodes and the metal component. The thermocouple's thermal emf is tapped off at the point 5 whose temperature is assumed to differ from that existing at the location of the junction.

We have studied a thermocouple with one film electrode, whose second electrode consisted of the component shown in Fig. 1a.

The circuit for measuring and recording the basic characteristics of a film thermocouple (Fig. 2b) is intended for a general case when it is impossible to select conductors which are thermoelectrically identical to the film electrode and the component. In this case it is necessary to select wire electrodes C and D whose characteristic $E_{CD}(t_0, 0)$ is similar to the basic characteristic $E_{AB}(t_0, 0)$ of the thermocouple comprising A (nickel) and B (material of the component), where $t_0$ is the temperature in the area where the wire electrodes are connected to the film ones. The ends of the wire electrodes are thermostatically controlled at the point with the temperature $t = 0$, where they are connected by means of copper conductors to the measuring instrument. If the junction is at the temperature $t$ (with $t \neq t_0$), which is measured with a reference thermocouple, it is possible to write

$$E_{AB}(t, 0) = E + \Lambda; \Lambda = E_{AB}(t_0, 0) - E_{CD}(t_0, 0),$$

where $E$ is the emf measured on the potentiometer.

This formula and the circuits corresponding to it are basic for measuring components under working conditions. The temperature $t_0$ of the joint can be measured over a wide range, depending on the type of components and the measuring conditions. For instance, in measuring by means of film thermocouples the temperature of gas turbine blades, the compensating wires were connected to the films in the area of the blade stem. The value of $t_0$ then attains 500-600°C. In the investigations made with typical specimens we used a simpler circuit entailing the thermostatic control of the joint at the temperature $t_0 = 0$. The possibility of using such a circuit was determined by the structure of the miniature furnace.

Nickel was selected as the material for the film electrode, since it possesses several advantages, namely, it oxidizes moderately at temperatures of 900-1000°C; it remains stable in various chemically active media; it is one of the most convenient metals for coating by the methods of evaporation in vacuum and electrical or chemical precipitation. When the nickel wire has been raised to the temperature at which active oxidation begins (700-800°C) and ex-
posed for a long time to 1000°C, it retains its thermoelectric properties, since the oxide film on its surface protects its inner layers from oxidation. The thermoelectric stability of nickel at temperatures up to 1000°C depends to a great extent on its chemical purity, and when it attains 99.95% the stability is adequate [1].

The nickel film was obtained by the vacuum evaporation method. The equipment for vacuum evaporation and condensation of thin films, which was used by us, was developed by the metal physics department of the V. I. Lenin Khar’kov Polytechnical Institute. The evaporator consisted of an alundum crucible. Separate heaters were used for raising the temperature of the backing before evaporation, for maintaining the required temperature during evaporation, and for the subsequent thermal treatment of films. A similar heater was designed for applying thermocouple films to the surface of gas turbine blades. The heater consisted of the heating element proper and a massive copper plate the shape of whose surface corresponded to the blade profile.

Typical specimens consisting of plates made of thermometric and special heat-resisting alloys (chromel, alumel, \(\theta1-435\), \(\theta1-109\), ZhS6-K and others) were prepared for studying film thermocouples. The structure of specimens shown in Fig. 1c and their adopted dimensions made it possible to spray a set of six specimens simultaneously.

We investigated the following properties:

a) the relationship of the thermal emf of a film thermocouple to the junction temperature (basic characteristic of a thermocouple);

b) the stability and reproducibility of the basic characteristic;

c) the resistance of the film electrode and of the junction to high-temperature corrosion (oxidation);

d) the thermoelectric nonuniformity of the film electrode along its length;

e) the physical characteristics of the film;

f) the effect of the thermal treatment of the film on its properties.

The stability and reproducibility of the thermocouple readings were investigated by plotting and then comparing the basic calibration characteristics obtained by repeatedly heating the thermocouples up to temperatures of 500, 600, ..., 1000°C with exposures for 15 min at each temperature. The last stage consisted of heating the thermocouple up to 1000°C, maintaining it at that temperature, and measuring continuously its thermal emf until a complete oxidation of its film occurred.