ERRORS IN TESTING SOLDERING BY THE THERMAL METHOD

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Reliable operation of turbo- and hydrogenerators depends to a great extent on the quality of soldered joints in current-carrying connections, and in particular, on the stator-winding conductors.

The existing soldering technology of the above connections is imperfect and requires effective inspection. The VNIIElektromash (All-Union Scientific Research Institute of Electrical Machinery) has developed a thermal method of checking soldered joints, which consists of the following. The generator’s stator-winding conductors are soldered and then connected in series to the tested generator and heated up with a current 50% above the nominal value to a temperature exceeding the ambient by 45°C. The temperature difference between the sleeve and the conductor is then measured by means of needle-shaped constantan thermocouples. This temperature depends unambiguously on the quality of the soldered joint.

Below we provide the results of investigations made for the clarification of this technique. These results were used in designing instrument AKP-2 adopted at the "Elektrotyazhmash" (Heavy Electrical Engineering) plant.

Investigation of the thermal emf measuring circuit. The thermoelectrical circuit for the above case is shown in Fig. 1. The total thermal emf of the series-connected thermocouples is equal to

\[ E = E_{AB}(t_0) + E_{BC}(t_0) + E_{CD}(t_1) + E_{DF}(t_0) + E_{GH}(t_0) + E_{HI}(t_2) + E_{IA}(t_3). \]  

Since

\[ E_{DF}(t_0) + E_{GH}(t_0) = 0, \]

we finally obtain

\[ E = E_{AB}(t_0) + E_{BC}(t_0) + E_{CD}(t_1) + E_{HI}(t_2) + E_{IA}(t_3). \]  

The thermal emfs of the differentially connected thermocouples (constantan-copper) consisting of that of the conductor \([E_{IA}(t_3)]\) and of the sleeve \([E_{BC}(t_2)]\) are effective; the remaining are stray-circuit emfs which produce measurement errors evaluated below.

Constantan-constantan thermocouples of different melts. It is known that constantan wires differ considerably in their thermoelectric properties.

In order to evaluate the thermal emf of a couple in a thermoelectrical circuit consisting of two different constantan wires we made two thermocouples with one electrode in each consisting of 1.8-mm constantan wire of the same melt, and the other electrode of 0.29- and 0.3-mm wires of different melts. The hot junctions of the thermocouples were immersed in boiling water, and the cold junctions connected to measuring instrument M-95.

These tests showed that the thermal emf of the 1.8- and 0.29-mm wires amounted to 0.079 mV, and that of the 1.8- and 0.3-mm wires to 0.011 mV, which, expressed in terms of degrees by means of the calibration curve of copper-constantan thermocouples, amounts to 1.7 and 0.25°C.

The error thus contributed is negligibly small, since the temperature difference measured between the sleeve and the conductor is normally smaller than 5°C, and that between \(t_1\) and \(t_2\) is even smaller.
Thermocouples consisting of the sleeve and conductor copper. For the evaluation of the thermal emf of such a couple \(E_{AB}(t_0)\) we made a thermocouple of copper brand MGM (of the conductor) and brand MZ (of the sleeve). The operating end of the thermocouple was immersed into heated water, and the free end, which was at the temperature of the ambient air, was connected to instrument M-95. The table shows the thermal emf of the copper brand MGM-MZ thermocouple with respect to temperature.

Since the absolute temperature of the sleeve to conductor junction varies in the course of testing (15 min) from 60-70 to 45-55°C, the thermal emf varies accordingly from 0.016-0.019 to 0.012-0.015 mV, which, according to the copper-constantan calibration curve, corresponds to 0.36-0.43 to 0.26-0.33°C.

Thus, in checking the operation of machines a constant error of 0.26-0.33°C is contributed to the measurements as well as a variable error whose maximum value amounts to 0.1°C. The former error can easily be eliminated and, therefore, is not taken into consideration in the course of measurements.

Investigation, selection, design and calibration of needle-shaped thermocouples. It is known that the value of the contact resistance between the thermal electrodes and the body with which they make contact has an effect on the measurement results if the recording instrument consists of a low-resistance millivoltmeter.

We investigated the effect of the shape of the thermal electrode point on the thermal and electrical contacts. Cone-shaped operating ends of pointed thermocouples were pressed into a copper sample between two of whose points a controllable temperature difference of 1-5°C was produced (when the sample was heated up to 60-70°C). The indicating instrument consisted of a millivolt-microammeter type M-95.

The slightest sloping of the thermocouples or variation in their pressure against the sample changed the measurement results by a factor of 2-3. The indentation of conductor 1 and the sleeve at the point of the thermocouple contact (optimum shape of the indentation is shown in Fig. 2), as well as the selection of the optimum shape for the point of the thermal electrode 2, provided a reliable thermal and electrical contact which ensured good repeatability of measurement results (deviations remained in the range of ±0.01°C). The contact between constantan and copper is then attained along a circumference instead of a single point.

On the basis of the results thus obtained we designed thermocouples (Fig. 3) which were made in the following manner. Constantan wires 1 and 2 were selected so that their couple produced an emf as close to zero as possible. Wire 1 of each thermocouple was taken from one coil and wire 2 from another. Wire 1 was taken outside the needle which consisted of constantan wire 2 and protruded 4-5 mm outside the bush was sharpened as shown in Fig. 2.

With such an arrangement of the thermocouple the errors due to the presence in the thermoelectric circuit of spurious contact couples is reduced to a minimum and depends only on the thermal emf between the copper of the sleeve and the copper of the conductor, as well as on the quality of the thermal and electrical contacts. These errors lie in the range of +0.05 to −0.25°C. The readings are virtually independent of the slope of the thermocouple contacts or of the pressure on them; they remain constant with time and provide good reproducibility of results.

The thermocouples were calibrated in the range of 45-70°C (the temperature variation range of a heated machine). For this purpose the temperature characteristics of two thermocouples connected differentially were compared. They were pressed against copper foil immersed in heated oil. No deflections from the zero position could...