OPERATING PROBLEMS OF THE THERMOCOUPLES IN VVER

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1. INTRODUCTION

The paper is devoted to the problem of the diagnostic accompaniment of the in-core temperature measurements.

In the VVER reactor the coolant temperature at the outlet of the most fuel assemblies is measured with chromel-alumel cable thermocouples (TC), placed in protective temperature-monitoring coverings-thermowells (TMC). The coolant temperature in main circulation loops is monitored with TC and resistance thermometers (RT).

The normal TC are 4mm and 1.5mm in diameter. The second type TC are enclosed into steel sheaths of diameter 4mm. These TCs are inserted into 7m long bent TMC. The TMC inner diameter is 8mm. There are non-hermetic TMCs. In this case the "hot" legs of TC are placed immediately into the coolant.

2. INSERTION OF TC INTO TMC

When a TC inserted into a TMC, it is necessary to check that the TC tip with the "hot" junction fits into the TMC seat. If the sensing tip of the TC cable is not fit into the receptacle, then the thermal resistance of the gap between the cable tip and the TMC seat rises, which, in turn, increases both the dynamic error of the measurements as well as the error due to the radiative heating of the TC.

The portable unit has been created for the in-sity testing of the quality of the TC insertion into the TMS. The set of current pulses is passed through the TC wires and TC sheath. The current is heated the sensor and a curve of the heating-cooling of it is recorded and processed.

The simple modification of this technique is based on the analysis of the amplitude of the signal from the TC after they are heated by one electric-current pulse. The experimental data for different insertions of TC into the TMC adapters of the VVER-440 reactor were obtained during scheduled maintenance in 1990 at the Rovno NPP. The TC was tested while the experimental setup was placed on the shielding tube unit (STU) plate in the control shaft /1/.

3. SYSTEMATIC ERRORS IN TEMPERATURE MEASUREMENTS

The errors in the temperature measurements are normalized and should not exceed 1C for the TC with individual calibration (at the 0.95 fiducial probability). There are methods for determining and compensation for the most important components of the systematic error. To increase the usability of these techniques of the validation of the temperature sensors, personal-computer-based, portable data-acquisition system is being developed.

3.1. Error due to calibration drift

The error due to the TC calibration-characteristic drift can be in the main compensated for the calibration performed periodically during the heating and hot test runs of the reactor after refueling.

One can derive the multiplicative or additive correction that balances out the deviation in the TC readings from the mean temperature averaged over the readings of all the TC above the core and/or loop sensors.

When there are gradients in the temperature field over the core during the calibration, the averaging of the temperature over the core may introduce a considerable contribution to the error of the corrections. In this case, the calibration can be provided by comparing the readings of some calibrating TC above the core with the temperature defined as the sum of the PRT-temperatures measured in the cold legs of the loops and weighed with the regard fractions of the coolant flow rate through the fuel assembly with this TC, which are accounted for by the flow rates through the corresponding loops. The determination of these fractions is carried out before the calibration /2/.

In the beginning of the TC operation the calibrations can undergo the positive drift. When the first calibration of the just installed TC is performed, account must be taken of the effect of the moisture diffusion along the insulation of TC wires to its "cold" junctions with the reactor at power. Then the negative drift is observed. This drift is caused by the oxidation of TC wires.

Sometimes there is a reason to believe that the calibration-characteristic drift of some monitoring loops is accounted for by that different elements or connectors of the monitoring loops. The techniques of redundant measurements is used for the identification of these elements.

3.2. Errors due to radiation heating and response time

The transfer vector-function and the vectors of statical coefficients can be obtained for a sensitive element of the temperature sensor /3/.

Let us suppose that we know these coefficients and the transer function. Then we can calculate the error due to radiation heating D or the response time of the TC tr. There is a close relationship between the error due to radiation heating and the dynamic error. We can calculate the error due to radiation heating D from the equation $D=D(q1,tr)$, where q1 is the specific radiation-induced heat. On the other hand, let us suppose that we know D. Then we can calculate tr from the equation $tr=tr(D,q1)$ /4/.

>From experiments on the VVER-440 reactor it was found that the TC installed over the fuel assemblies in the hermetic air-filled TMC (well-type T1) overestimate the readings as compared with the symmetrical the TC (wet-type T2) installed immediately to the coolant. The difference of readings (T1-T2) due to the radiation heating was 0.85C /5/.

The response time of TC can be estimated by means of in-situ testing of the TC as noted above /1/.

3.3. Errors due to the flow stratification of the coolant

The area-averaged temperatures are a matter of interest to the plant operators. (There are the core-, loor- assembly-averaged temperatures). Given inhomogeneous temperature pattern, the actual temperature readings may be differed from the area-averaged temperatures due to effects of the primary coolant flow stratification. (There are the incomplete reactor mixing of the coolant from various loops; the flow stratification in hot legs of primary system; the streaming effect above fuel assemblies) /6/.

One can estimate the incomplete reactor mixing of the coolant during the heating of the primary system (at zero reactor power). Such incomplete mixing can be diagnosed from the histograms for the deviations in the readings of the above assemblies TC's from the mean temperature. A nonstationary and inhomogeneous distribution over the core can be produced especially /2/ and then obtained the influence coefficients of the loops on a fuel assembly.

Research has shown that the differences of loop-thermo-sensors readings of some VVER-1000 hot leg are functions of a motion of the reactivity compensation rods because there is the flow stratification in the hot legs of the loops. It was established that the temperature of the coolant flow from a definite part of the core only affects the readings of any sensor. (It is of interest that there is not the coincidence between the areas of the influence of hot- and cold-leg sensors for some loop. Thisnon-coincidence leads to errors in loop heating measurements).

There are the codes for estimations of micro structure of heat production pattern in the interior of the assembly. These codes provide a way for an estimation of the correction factor for TC's which are placed above the assemblies. This effect is particularly pronounced for the assemblies incorporating the rods with burning-out absorbers.

4. AGING OF TC

The aging of TC can be determined without removing these TC on the basis both of the periodic calibration operations and of the in-situ inspections.

It is interesting to note that the calibration drift was only slightly dependent on the irradiation conditions in the "hot"-junction area. This is so at least with working times shorter than 10E5h and neutron fluences in the region of the "hot" junction lower than 10E21 neutron/(sq.cm). The electrodes in the TC located above the core in the VVER are in a quasi-isothermal coolant flow zone throughout their seven-meter lengths. The main temperature drop along the TC occurs in the region of the upper plate in the STU, i.e., at more than 6m from the core. The neutron fluence is much less in the non-isothermal region than is the fluence in the "hot"-

junction one. The same applies to the radiation-defect distribution along the TC. (The "hot" ends of the TC are substantially embrittled only over a length of about 0.3m). On the other hand, deviations from the thermoelectric homogeneity, including those due to irradiation, can not affect the readings if the sections of the electrodes with disturbed homogeneity lie in the isothermal region. Thus, it may concluded that the calibration drift for TC measuring the coolant temperature at the outlet of the core in the VVER is primarily due to ageing of not radiation origin. One of the basic factors governing the TC life is difficulties associated with TC removal for replacement.

5. REMOVAL OF TC FROM RADIOACTIVE TMC

The experience shows that the removal of TC from TMC presents some difficulties. Sometimes attempts to remove the TC can lead to the open-circuit of it and, hence, to the difficulty of the instalation of a new TC into the TMC. Various techniques for removal of stuck TC has been developed /7/.

The first reason for jam is the infiltration of the coolant with boron acid through microcracks into the TMC and precipitation of boron anhydride (BA) in it. The BA crystal led to the TC sticking. Another reason of the open-circuit is the sticking of the embrittled TC tips in the TMC bends. The sticking of the TC tips in the TMC adaptors should also be pointed out. The TC break is accounted for by stress corrosion cracking in the vicinity of the "cold" TC junction because of the presence of moisture in the TC insulation.

In sticking of TC a special "stocking" is put on it to reduce the friction between TC and TMC. Then the sluicing solution is injected into the "stocking" to wash out of the BA cork. To facilitate the cork removal the supersonic attack can be applied to the TC.

The TC can be broken at the needed depth by local heating at this depth using a special microheater. The broken TC can be connected to the probe by the remotely operated welding.

It should be emphasized here that the radiation conditions at the time of the TC are replacement present difficulties for operations below the STU plate. All operations are conducted at the seven-meter depth inside the TMC (8 mm I.D.).

6. CONCLUSION

The calibration-performances of TC will be changed in the course of the irradiation cycle. These TC can be calibrated by means of the loops RT at points in the calibrate range being obtained during heating of the reactor by non-homogenious temperature field in the primary circuit.

Both the error due to radiation heating and the dynamic error depend on the thermal resistance between the TMC adapter and the TC tip. This resistance can be obtained by means of in-situ TC testing. The portable unit has been developed for this techniques.

The irradiation is not the main cause of calibration drift for neutron fluences in the hot-junction region less than 10E21neutron/(sq.cm).

The TC life is determined by difficulties occuring during the removal of the TC for replacement. Because of this, the regular diagnostic tests of TC is required for the determination of its condition.

Thus the proposed techniques can be used to diagnostic accompaniment of the reactor temperature measurements by means of the TC from their "birth" to storage. The special data-acquisition unit for the validation of the temperature sensors has been created. The unit is portable and intended for deployment when and where needed.

NOMENCLATURE

D is the error due to radiation heating; ql is the specific radiation-induced heat; tr is the response time of TC.

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