Non-destructive methods of control of thermo-physical properties of fuel rods

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Abstract. Information about the change of thermal properties of the fuel elements needed for a successful and safe operation of the nuclear power plant. At present, the existing amount of information on the fuel thermal conductivity change and "fuel-shell" thermal resistance is insufficient. Also, there is no technique that would allow for the measurement of these properties on the non-destructive way of irradiated fuel elements. We propose a method of measuring the thermal conductivity of the fuel in the fuel element and the contact thermal resistance between the fuel and the shell without damaging the integrity of the fuel element, which is based on laser flash method. The description of the experimental setup, implementing methodology, experiments scheme. The results of test experiments on mock-ups of the fuel elements and their comparison with reference data, as well as the results of numerical modeling of thermal processes that occur during the measurement. Displaying harmonization of numerical calculation with the experimental thermograms layout shell portions of the fuel cell, confirming the correctness of the calculation model.

1. Introduction

Justification of safety and efficiency of the reactor’s cores require reliable data on the thermo-physical properties of the fuel elements and change them during the campaign. At present, such data are available for the fuel rods with the oxide nuclear fuel, but in the range of averages burnup to about 5% of heavy atoms. For new fuel types (modified uranium dioxide, dispersion, dense uranium-plutonium) data on changes in the thermal conductivity of the fuel ($\lambda_f$) and the contact thermal resistance ($r_c$) between the fuel and cladding during the campaign are practically absent.

Earlier studies have been carried out changes of thermal properties of nuclear fuel ($\lambda_i$ and $r_i$) from burning out. The measurements were performed on samples obtained after opening the fuel cladding. On the thermal conductivity of the fuel pellets affect accumulated fission products produced gas pores, radiation damage, changes in the morphology of the initial process of porosity and cracking of tablets. The thermal conductivity of the contact between the fuel and cladding depends on the gap between the fuel and cladding due to swelling of the fuel cladding geometry changes under the shell and release of fission gases. These changes, occurring in a fuel rod during operation, shows that authentic data only non-destructive measurement techniques are available for thermal conductivity and thermal contact resistance.
2. Current development
Heat-conducting properties of the problem of measuring rods and solved earlier. In particular, in [1, 2] is a description of non-destructive methods of measurement of thermal properties. These procedures are based on heating the cladding current pulse duration of 0.01 seconds and registration of changes in the surface temperature of the fuel element after the pulse. Typical process times reduce the temperature naturally associated with the contact thermal resistance and thermal conductivity of the fuel, can determine $\lambda_t$ and $r_c$ in a single experiment. However, the technique of heating current pulse envelope applicable to fuel elements containing the electrically conductive nitride, carbide, metallic fuel. Non-destructive methods of investigation of fuel rods with a conductive fuel can be accomplished using a shell fragment heating fuel rod laser pulses.

3. Method local heating by laser radiation
At the Department of Thermal Physics of MEPhI the technique of implementing non-destructive measurement of thermal properties of the fuel rods, which can be applied in a protective box. Schematic diagram of the experimental setup is shown in Figure 1.

![Diagram](image)

1 – fuel rod; 2 – laser; 3 – pyrometer; 4 – selective mirror

Figure 1. Schematic of the Installation.

On the surface of the fuel rod cladding given pulse of laser radiation, which heats a shell fragment. With pyrometer temperature heating is carried out during the registration point of the laser pulse duration of action 0.5 - 1 s and after its completion. You can determine the value of the contact thermal resistance $r_c$, defining characteristic decay time temperature heating point after the laser pulse. Fuel thermal conductivity measurement is carried out by the characteristic temperature rise time at the point opposite the point of heating. In this experiment, using heat pulses 4 - 6 seconds.

Determinat $r_c$ and $\lambda_t$ by the experimental thermograms carried out using the results of numerical simulation of the thermal process in a fuel rod.

4. Test experiments
Experiments were carried out on cylindrical samples and mock-ups of the fuel elements for the verification procedure efficiency. The test samples and layouts cylindrical rods were placed in a special temperature controlled oven and inspection openings for introducing laser radiation pyrometer and recording temperature.

In the first stage, experiments were conducted on cylinders №1 and №2 of steel 321 to demonstrate the correctness of the pyrometer and the computational model. Cylinder №1 had $\varnothing8,1$ mm diameter and 40 mm of height and cylinder №2 had $\varnothing7,4$ mm diameter and 15 mm of height.

Figure 2 shows a comparison of the calculated and experimental thermograms in terms of heating and diametrically opposite point.
Figure 2. Thermograms of heating (A) and the diametrically opposite point (B) (cylinder №1).

Figure 2 shows a satisfactory agreement between the calculated and experimental thermal images, which indicates the accuracy of modelling of thermal processes in the program of a numerical calculation.

Figure 3 shows the results of measurement of the thermal conductivity by the described method on the cylinders of steel 321.

The obtained data according with the reference data [3] within the 5% error.

In the second stage were measured on mock-ups of the fuel elements from the shells of steel 321, EK-164, filled cylinders of steel 321 that simulated nuclear fuel. Internal volumes of fuel rods filled layouts helium or argon pressurized 2 atmospheres. The diameters and shell thicknesses were $\varnothing 8.1 \times 0.35$ mm (st. 321) and $\varnothing 9.38 \times 0.49$ mm (EK-164). The outer diameter of the cylinder inside the sheath was made of 0.05 - 0.1 mm less than the inner diameter of the shell.

Figure 4 shows the results of measuring the thermal conductivity of the cylinder of steel 321, Figure 5 - contact thermal resistance between the cylinder and the shell.

Figure 4 shows a satisfactory match of data of thermal conductivity for steel 321 obtained in the experiment, with reference data.

Measurement error magnitude $r_c$ does not exceed 30%, $\lambda_t$ - 10%.
5. Conclusion
We propose a method of non-destructive testing of thermal properties of the fuel elements from nuclear power conductive fuel. The measurement results obtained in the model fuel rods, show quite satisfactory performance techniques.

References
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