Development of a method for determining corrosion damage of fuel element claddings of a nuclear power unit by using acoustic resonance method in a hot chamber environment

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Abstract: As part of the strategic research program of state corporation Rosatom, carried out by the Technological Platform "Closed Nuclear Fuel Cycle with Fast Neutron Reactors", a research to equip protective cells with original equipment, including ultrasonic flaw detectors for primary post-reactor non-destructive research of the properties of critical materials of fast neutron reactors, is being performed. In this paper, we present a method developed for determining corrosion damage of fuel claddings by the acoustic resonance method in hot chamber conditions, and a description of the experimental installation.

1. Introduction
Corrosive damage of fuel element claddings (fuel rods) is the main cause of their depressurization and contamination by fission products located in the primary circuit of the nuclear power plant [1]. Experience gained by operating fuel rods of fast-neutron reactors shows that the main difficulty to achieve high burn-ups is corrosion damage of the shells by the fuel. Also, the current level of development of nuclear energy requires almost 100% tightness of the shells during the entire period of their operation. It is impossible to achieve these indicators without thorough post-reactor studies of spent fuel rods, which are currently being conducted in such large research centers as JSC "SSC RIAR" and JSC "IRM" equipped by complex of hot cells and special equipment.

2. The principle of measurement
The developed installation measures corrosive damage of the fuel elements` shells by ultrasonic resonant method, the essence of which is as follows: two piezoelectric transducers are brought into contact in diametrically opposite points of the fuel cladding. The first piezoelectric element is initiating the waves, the second is receiving. The measuring unit consists of two pairs of dampers (absorbers) and two piezoelectric transducers. Piezoelectric transducers are located by special holders that provide spring-loaded contact with the fuel cladding. Dampers are necessary to ensure the specified boundary conditions on the measured portion of the fuel rod. During the measurements normal waves (Lamb waves) are initiated in the examined shell, the value of the frequencies and quality factors of waves depend on corrosion damage [2].

3. Producing and preparing of the test sample
In order to investigate different types of corrosion it is necessary to prepare samples for research. Obviously, it is required to create conditions, which provide crushing of the fuel element cladding at

the same conditions as in actual operating ones. For testing the method and obtaining the main experimental dependencies sections of pipes made of steel H16H15M3BR (diameter of 6.9 mm and a length of 80 mm), which were placed in a 10% solution of ferric chloride, were used as samples. To accelerate the corrosion process an electric current of 30 mA / cm2 was passed through the pipes. Figure 1 shows shell of fuel element containing areas with and without corrosion damage after 30 minutes of etching.

Figure 1. Fuel cladding subjected to electrochemical corrosion.

To obtain numerical data of the dependence of corrosion effect of on the resonant characteristics of the shells, step-by-step studies were carried out. The corrosion time of holding samples in ferric chloride was 15 and 30 minutes. After each stage, the samples were washed by water, dried, and their roughnesses were measured by using a profilometer, as well as resonant frequencies and Q-values of informative harmonics. Typical shell surface profiles for various corrosion times are shown in Figure 2.

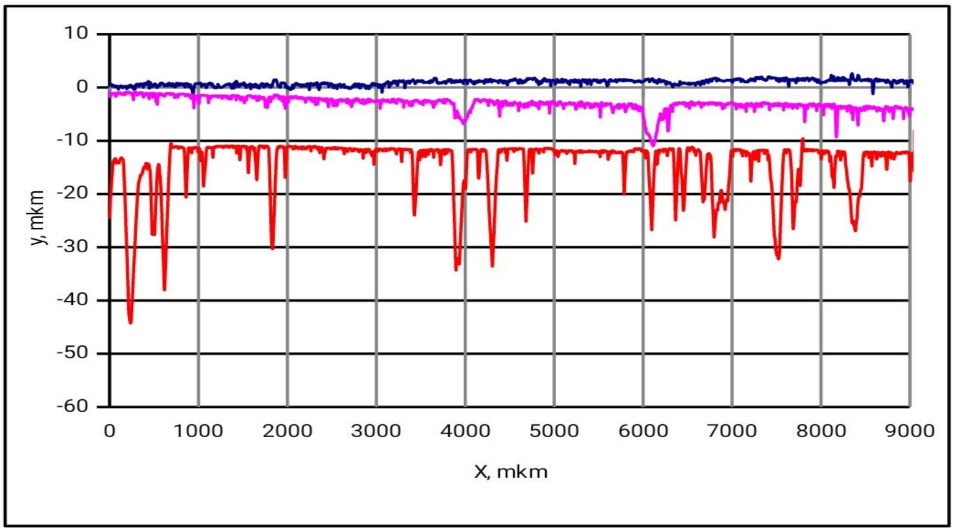

Figure 2. Typical shell surface profiles for corrosion time (0, 15, 30 minutes, respectively).

According to figure 2 increase of the corrosion time leads to growing in both the number of pits and their depth on the sample surface, which is a consequence of increase of the roughness of the shell surface. During the etching shell thickness was reduced and the degree of pitting corrosion increased, which led to decrease of as the informative resonant frequencies as the quality factor of oscillations due to wave scattering on the shell inhomogeneities.

The dependence of the roughness values Rq, Rmax, Ra, Rz of the shell surface profile on the corrosion time is shown in Figure 3.

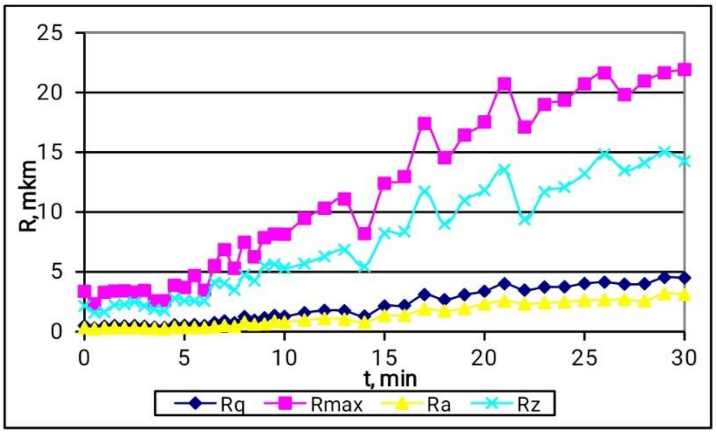

Figure 3. Dependence of roughness values Rmax (Ry), Rz, Ra, Rq the surface profile of the shell on the time of corrosion.

According to figure 3 during pitting corrosion the roughness parameter Rmax, which is responsible for the depth of the maximum depth of corrosion damage, changes most of the all. Therefore, subsequently it is selected as informative parameter of shell damage.

4. Approbation of the method

As a result experimental graphs of the resonant frequency (Figure 4) and quality factor (Figure 5) of informative resonance for intact fuel element claddings on the surface roughness Rmax were obtained, that allow evaluating both the average thinning of the cladding and the depth of pitting corrosion.

Corrosive damage of the shell leads to a shift of localized resonances to the low-frequency area, which is connected with thinning of the average shell thickness [3]. In this case, the Q-factors of low-frequency resonances change slightly, while the Q-factor of the high-frequency informative resonance decreases deeply. This circumstance could be explained by scattering of high-frequency waves on shell inhomogeneities caused by pitting corrosion. This effect performs as a diagnostic signal for evaluation of the degree of corrosion damage for thickness and depth of pits of the fuel cladding. In this case, the wall thickness could be determined by the values of the resonant frequencies of the higher harmonics of localized oscillations, and the depth of pitting corrosion – by their quality factor. The degradation of the physical-mechanical properties of the shell material due to swelling process could be determined by the values of the lower resonance frequencies [4]. The method can be applied both for long shells during their scanning and standard shells of 30 mm in length, used during the study of spent fuel elements in IRM JSC.

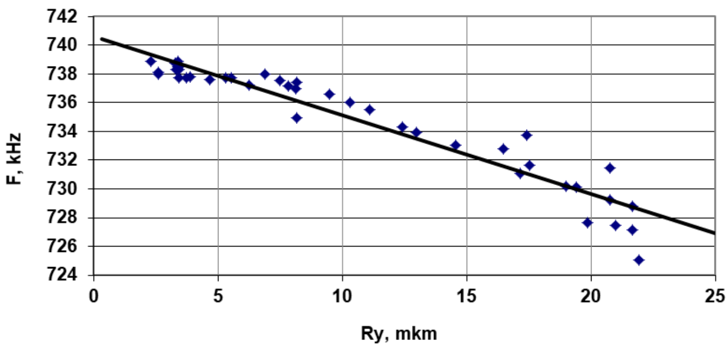

Figure 4. The dependence of the frequency of the informative resonance on Rmax of the shell surface.

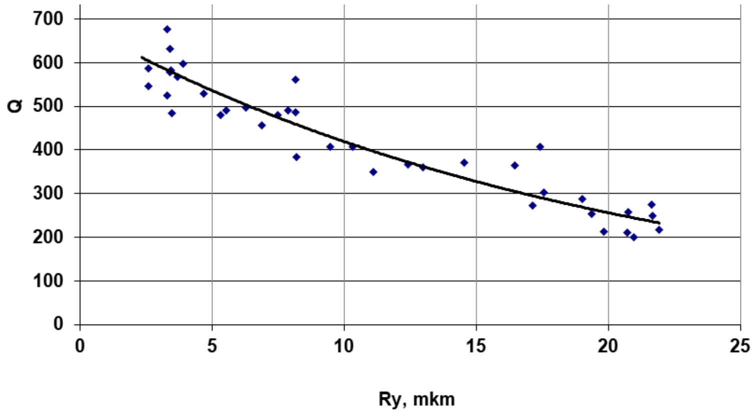

Figure 5. The dependence of the Q-factor on the informative resonance on Rmax of the shell surface.

5. Conclusion

The results confirm that the resonance method is prospective both to control the fuel element claddings during their production and to evaluate their damage during operation, including evaluation of degradation of the physical and mechanical properties during swelling and corrosion with separation of the thinning effect of the cladding and the value of local (pitting) corrosion.

Acknowledgments

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