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In-service change in the flexural rigidity of the VVER-1000 fuel assemblies

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Abstract

In-service dimensional stability of the VVER-1000 reactor fuel assemblies (FA) depends to a great extent on their flexural rigidity. A decrease in the flexural rigidity in the process of the FA operation in the reactor may lead to such FA bowing as will make it difficult for the absorber rods of the reactor control and protection system to move in the FA guide channels. This is not admissible from the point of view of the reactor operation safety.

This paper describes a method and a facility for the hot cell testing of the irradiated VVER-1000 FA flexural rigidity. The method is based on measurements of the FA bowing induced by cross-sectional loading. The load applied to the spacer grids is perpendicular to the grid face, and the FA bowing is measured optically using a TV camera. The facility can also be used to test the flexural rigidity of the FA skeleton after all of the fuel rods are removed. Several tens of VVER-1000 FAs with a burnup of ~4 to ~65 MW day/kg U were tested by Dimitrovgrad Research Institute of Atomic Reactors. The generalization and an analysis of the test results have made it possible to identify the major factors that contribute to the in-service change in the flexural rigidity of the VVER-1000 FAs and to determine the experimental dependence of its change on burnup.

It has been shown that an increase in the burnup causes the flexural rigidity of TVSA and TVS-2 FAs with a rigid skeleton to decrease to the minimum value of ~5 kg f/mm, the burnup being 45–50 MW day/kg U, and then to start growing again. It has been found out that it is the fuel bundle, specifically the change in the force of the fuel rod compression in the spacer grid, which is responsible for the change in the FA flexural rigidity. The maximum TVSA and TVS-2 FA bowing is in the range of 8–11 mm whereas the burnup is 48–63 MW day/kg U. The newly adopted TVSA and TVS-2 FA designs have contributed to the safe operation of the VVER-1000 control and protection system's absorber rods.

Keywords: Fuel assembly; Fuel rod; VVER; Flexural rigidity; Fuel burnup; Spacer grid; FA skeleton; FA bowing.

Safe operation of nuclear power units with VVER-1000 reactors depends to a great extent on the geometrical stability of the fuel assembly (FA) structure (bowing degree and shape, twist angle, length, lateral dimension, warping of spacer grids) throughout the operation period. The robustness of the reactor control and protection system's (CPS) absorber rods and the safety of the FA handling in the course of refueling depend on changes in the FA geometrical parameters.

To improve the neutronic performance of the VVER-1000 reactor cores, the commercial FA with a steel skeleton was replaced for an improved FA (IFA), in which the steel guide channels (GC) and spacer grids (SG) were substituted for zirconium ones. The spacer grids are attached to the FA central tube, and the GCs are attached in the FA tail support grid at the bottom and in the FA head at the top and run freely through the SG [1,2].

The results of studies on six IFAs at NIIAR have shown that it is as soon as after one fuel cycle (a burnup of 10–16 MW day/kg U) that the IFA bowing reaches ~15 mm and that it has a zigzag shape. The potential causes for the IFA bowing are axial loads from the reactor's safety tube block and lateral loads from the adjoining FAs, as well as the

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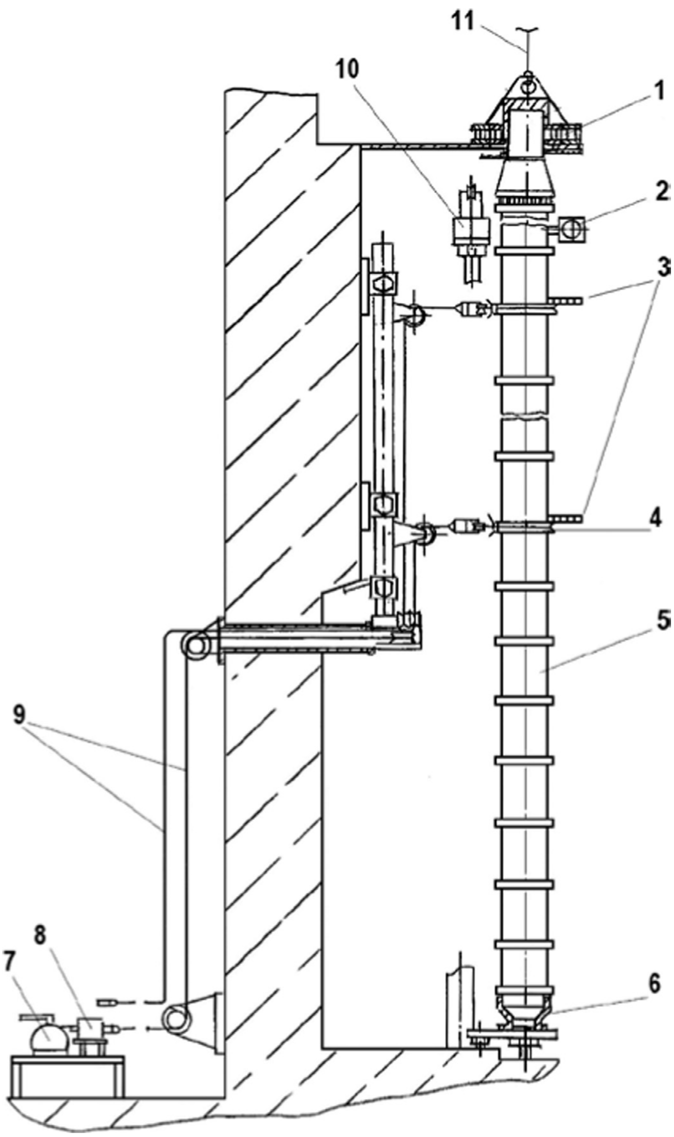

Fig. 1. Layout of the FA flexural rigidity measurement facility: 1 – FA head attachment; 2 – TV camera; 3 – measuring bar; 4 – force loading ring; 5 – FA; 6 – FA tail attachment; 7 – cable hoist; 8 – dynamometer; 9 – cables; 10 – TV camera rack; 11 – crane sling.

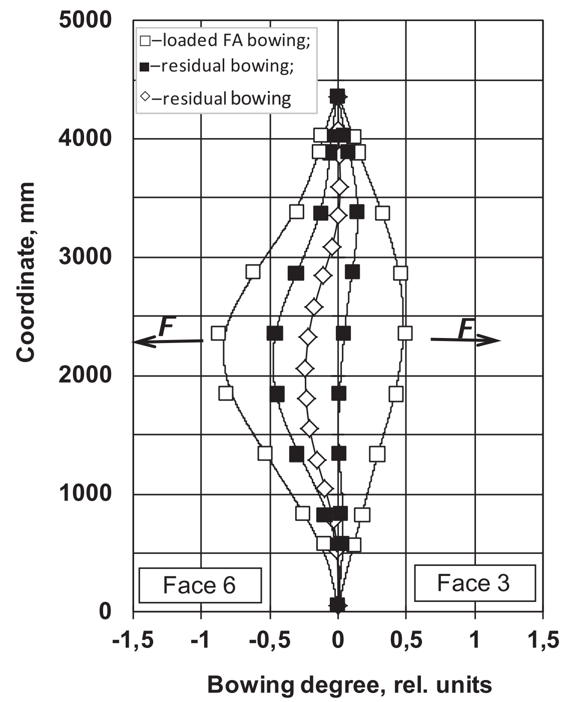

Fig. 2. FA axis shape during tests.

in-service decrease in the IFA flexural rigidity [3,4]. The bowing reaches 18 mm at a burnup of ~40 MW day/kg U. These two factors, the degree of bowing and its shape, have been found to be primarily responsible for the increase in the time of the CPS absorber rods drop in the FA GCs and even for the potential absorber rods sticking in the event of the reactor scram, which is not admissible in terms of the reactor safe operation [5,6].

A procedure and an hotcell facility have been developed at NIIAR to study the flexural rigidity of irradiated FAs based on determination of the FA flexural rigidity from the degree of bowing in conditions of lateral FA loads [6–8].

The facility (Fig. 1) consists of three major components: a force loading system, the FA attachments and an FA bowing measurement system with a TV camera moving along the FAs. The FA attachment inside the facility reproduces the attachment conditions in the reactor. The FA bowing is simulated through a load being perpendicularly applied to the faces at the level of the eighth or the twelfth spacer grid (respectively SG8 and SG12). The load is transferred through the force loading ring fit tightly onto the SG. A cable is connected to the ring which is led, with the use of rollers, through a shielded hotcell horizontal port into the operator room where it is connected to the force loading hoist via a dynamometer.

The load is applied to the SG in steps of 10 to 15 kg f with the load removal after each step, whereas a TV camera is used to measure the displacement of each SG in the FA. The results are processed and smoothed and the FA axis shape is restored during the loading and after the load is removed.

As an example, Fig. 2 presents the shape of the FA axis with SG8 being loaded in two opposite directions: in the direction from the FA's face 3 towards face 6 and vice versa. The figure also shows the shape of the initial bowing after the FA operation and of the residual bowing after the load removal. The residual bowing is caused by the interaction of the fuel cladding and the GCs with the spacer grids during loaded FA bowing. It is enough to suspend the assembly onto a crane and pull it slightly up for the bowing to disappear.

The FA flexural rigidity is characterized by the coefficient k_{FA} which is determined with an error of not more than 4% from the dependence of the bowing degree B on the applied load F (Fig. 3) [7]:

$$k_{FA} = dF/dB. \quad (1)$$

Normally, the coefficient k_{FA} is determined for the FA middle at the level of SG8 for the FA designs with fifteen grids.