Investigation of the fuel rod interaction forces on the spacer grid of Nuclear Fuel Assembly

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1. Introduction

The APR1400 nuclear fuel assembly is made up of various components such as fuel rods, spacer grids, guide tubes, in-core instrumentation, and top and bottom nozzle. Each of these components serves a unique function with the end goal of providing fuel for the nuclear reactor safely efficiently. The spacer grid supports the fuel rod and maintain the spacing between the fuel rods, provide for coolant mixing, and resist the external loads. The fuel assembly guide tubes which are the structural members of the skeleton assembly transmit the vertical loads between the top and bottom nozzles and position the fuel rods support grids vertically. They also react the loads from the fuel rods that are applied to the spacer grids and provide the lateral support and load capability for the overall fuel assembly [2]

The spacer grids which are the most important component of the fuel assembly provide lateral restraint to the fuel rod, therefore, maintaining the fuel rod array by providing frictional restraint in the axial direction. Contour springs are attached to the spacer grids and the contact between the spring and the fuel rod provides the support for the fuel rods. With the operation of the reactor and neutron irradiation in the reactor, stress relaxation of the spacer grid spring is induced and spring force reduces. As the cooling water flows it leads to vibration of the fuel rod resulting in damage at the contact area between the spring and fuel rods, known as fretting wear.

The fuel rods and spacer grids create non-linear friction force between the fuel rod tube and spring against the fuel assembly external lateral force. The rod grid interaction leads to fuel assembly lateral stiffness. This paper investigates the fuel rod friction force on the spacer grid for the APR1400 light-water nuclear reactors.

2. Methods and results

2.1 The spacer grid design

The spacer grid is made up of many unit spacer grid sets as shown in Figure 1.

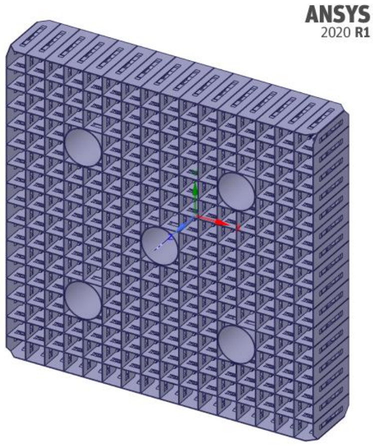

Figure 1 APR1400 Spacer grid set

It shows the spacer grid set as a combination of many unit spacer grid sets. A unit spacer grid consists of four spacer grids. The unit spacer grid cell with a fuel rod clad is shown in Figure 2.

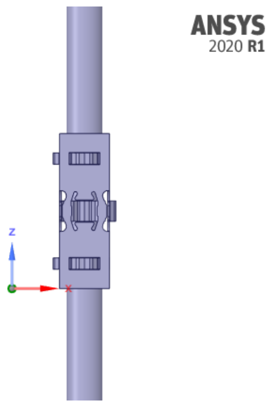

Figure 2 Unit Spacer grid cell and fuel rod clad

The structural performance of the four spacer grids is important for the support of the fuel rod. The fuel rods supporting parts in the spacer grids are the springs and dimples. When inserted into the spacer grid, most deformation takes place in the spring, because the dimple is stiffer.

The fuel rod-grid interaction exhibits nonlinear behavior making it hard to calculate flexural rigidity numerically.

Resistance to the lateral force of the fuel rod-grid interaction is a function of spring and dimple forces, and the coefficient of friction equation is shown in equation (1).

$$F_L = F_N + 2F_F = F_N + 2(\mu \times F_N) \qquad (1)$$

Where,

F_N- Spring/ dimple normal force

F_F -Friction force on spring & dimple

F_L- Lateral load on spacer grid

μ- Coefficient of friction

2.2 Mesh

For the analysis sufficient numbers of nodes and elements were generated in the three-dimensional model and are expected to give reliable results.
Mapped mesh presented in Figure 3 and applied in the 3D model using the linear element order and default element size.

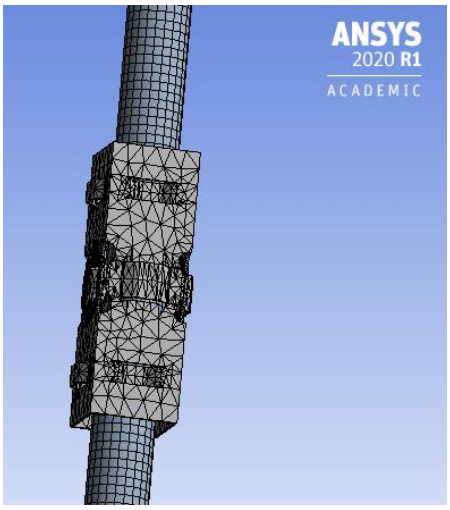

Figure 3 Mesh

The total number of generated nodes and elements are summarized in Table 1.

Table 1 Number of elements and Nodes

Item	Description
Node	15647
Element	14686

2.3. Boundary conditions and load application

The contact connection between the fuel rod clad and the grid spring inner surface was set as frictional contact.

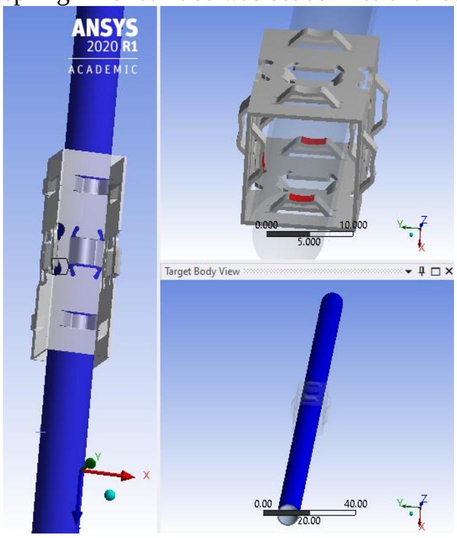

Figure 4 Frictional contact connection between fuel rod clad and spring inner contact surface

Fixed support was applied on the grid cell and the force applied on the fuel rod clad to counter the grid spring force. A force of 100 N was applied in the lateral direction.

2.4. Results

Applying the fixed support and the force boundary conditions, as well as the frictional contact, the analysis was run to get the deformation and equivalent stress in the fuel rod in each of the directions.

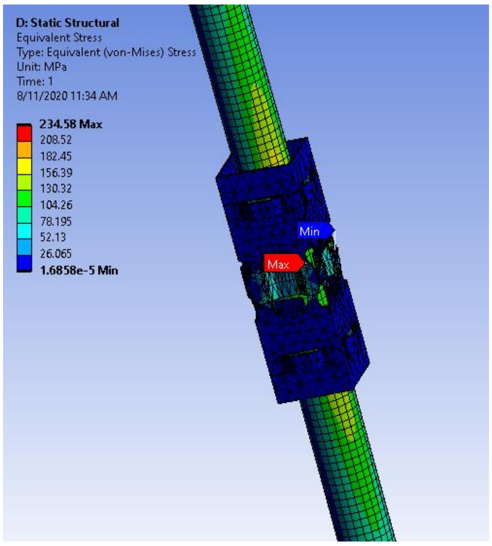

Figure 5 Equivalent stress

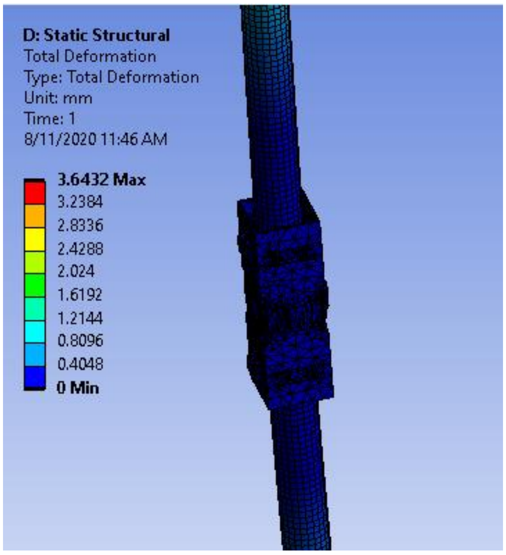

Figure 6 Total deformation

The maximum equivalent Von Mises stress was 234.58 MPa and occurred at the spring contact with the fuel rod clad. The maximum deformation was 3.6432 mm which is slightly over the test value of 2 mm.

Table 2 Force component against resulting deformation

Force component (N)	Total maximum deformation (mm)
100	3.6432
130	4.2635
170	5.2041
200	6.1881
230	9.489
270	42.714
300	89.603
330	148.72
370	241.02
400	316.89

Table 2 shows the resultant force component and the resulting maximum deflection. A curve showing this relationship is illustrated in Figure 7. It shows a nonlinear relationship similar to test results.

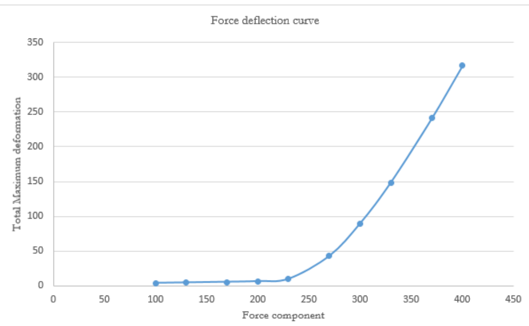

Figure 7 Applied force-deflection curve

3. Conclusions

The analysis was carried out on an individual grid cell to show the behavior of the entire fuel assembly. The lateral vibration and stiffness were compared to the test results.

The fuel rod-grid interactions show nonlinear behavior due to the slippage that occurs between the rod clad and the grid spring.

The grid dimples are stiffer and there's minimal deformation at the dimple locations.

Acknowledgment

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