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# An Analysis of GTRFW Initiation Using Finite Element Method

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**Abstract:** Understanding the Grid to rod fretting wear (GTRFW) initiation is critical for reducing the risk of fuel leak. In this paper, a simplified 3D FEA model is set up to analyze its mechanics. The initiation of GTRFW under a series of interferences was modeled and analyzed. It is found that slip and wear usually initiate from the edge of the grid to rod contact contour and eventually propagates to the entire contour. Due to the stress concentration, the contact at sharp corners should be avoided.

**Keywords:** GTRFW, Wear, Slip, PWR

## 1. Introduction

Fretting wear is a damage mechanism in many engineering applications [1-10]. GTRFW is a major cause of cladding failures in pressurized water reactors (PWR). GTRFW problems are caused by coolant-induced vibration and insufficient support [11]. In a PWR, the fuel rods are supported by preloaded spacer grids. Due to high temperature and irradiation, the preload force is relaxed. When the support becomes insufficient, the turbulent force due to the coolant causes vibrations. The relative motion between the contact surfaces of cladding and rod, i.e. grid to rod fretting, will then cause wear. Eventually, the fretting wear may cause fuel leak, which is a threat to the safety [11-14]. Therefore, an investigation of the initial creep process is crucial for understanding the initiation of fretting wear.

Both experimental and numeric analyses have been done to study the GTRFW problems. Kim et al. developed a testing rig to study the key factors of GTRFW problems. They found the transportation, fuel rod loading, coolant flow and grid to rod gap are critical factors [11, 15-21]. Through numeric simulations, Rubiolo et al. statistically characterized the force due to the coolant flow. They developed a 1 D model which allows modeling of factors such as excitation force and grid to rod gap on vibrations and wear. Hu et al. developed a novel wear modeling technique allowing efficient simulation of the GTRFW in 3D FEA models [22-26]. Through a systematic modeling of the gap sizes and excitation frequencies, they found the maximum wear rate is determined by a system resonance frequency, which is the root cause of the GTRFW [27]. The risk of GTRFW can be significantly reduced by avoiding the resonance frequency. Significant progress has also been made by Pu et al. in understanding the microscopic properties of materials in the reactor through innovative experiments and theoretical studies [28-33]. Efforts have also been made by Kim et al. to study the contact mechanics on the grid to rod interface [34-38]. It was found a concave spring contour would reduce the wear rate. In this paper, the initiation of GTRFW is modeled using a simplified 3D FEA model. Since the preload is closely related to the interference, a series of interferences are used to study their effects on the slip and wear.

## 2. Methodology

In a PWR, a unit cell of the spacer grid has a smaller size than that of the rod. Due to this interference fit, there will be a preload at the contact interface between the clad and the fuel rod [19]. This preload provides a static friction force, which will resist the potential relative motion. However, under high temperature and irradiation, creep strain becomes significant, which causes stress relaxation. The involvement of those factors would significantly increase the complexity in modeling the contact interface [39-42]. The turbulence of the coolant flow causes vibration. When the contact stress is relaxed by creep and wear, the vibration will eventually overcome the support force and cause fretting wear [11, 12]. Therefore, it is necessary to study the stress relaxation caused by creep and predict the critical scenario at which the fretting will occur.

To simulate this process, a simplified 3 D finite element model is built in the FEA code ABAQUS. The key dimensions is set up according to the real values as shown in Table 1 [37]. So there will be a preload on the contact interface between the grid and fuel rod. A Coulomb's friction law will be used to model the maximum static and friction stress, and the equation is as follows,

$$f = \sigma_c \mu \quad (1)$$

where $f$ is the critical friction stress when slip occurs, $\sigma_c$ is the contact pressure and $\mu$ is the friction coefficient. That means if the contact shear stress of at a node of the contact interface is equal to the friction stress, slip will occur there. When creep strain grows, the contact pressure at the interface will decrease, so the critical friction stress will decrease as well. When the contact shear stress is large enough to overcome the friction, slip will occur. Because the contact pressure and contact shear stress may be different from one location to another, the partial slip will occurs locally at the beginning and eventually becomes full slip. In this study, instead of modeling the creep evolution, a series of different interferences are used. Those interferences would provide different preload that represents different stages of stress relaxation.

***Table 1.*** *Key parameters of the FEA model.*

| | |
|---|---|
| Cladding thickness | 0.57 mm |
| Cladding diameter | 9.5 mm |
| Rod length (2 spans) | 150 mm |
| Density of Zircaloy 4 | 6.5×10-3 g/ mm³ |
| Young's modulus of Zircaloy 4 | 75 GPa |
| Poisson's ratio of Zircaloy 4 | 0.37 |

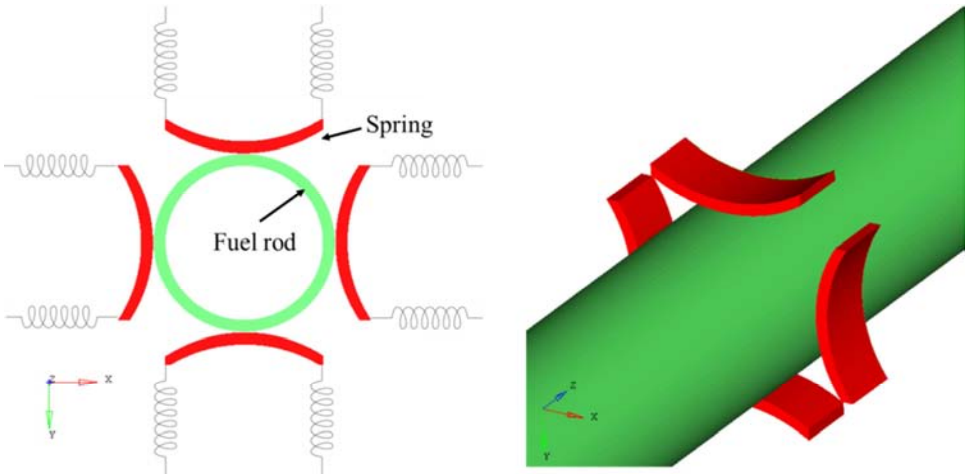


***Figure 1.*** *A simplified with a fuel rod supported by a simplified spacer grid.*

The FEM model is set up as shown in Figure 1. The assembly is composed by Zircaloy support springs and Zircaloy cladding. The detailed dimensions and material properties are listed in Table 1. The interference will be set up between the contact components through applying an initial displacement to the springs. Different interferences can be set up between the springs and the cladding in order to investigate their effect on the GTRFW. To simplify the study and eliminate the complexity of turbulent force, an axial displacement $D_a$ is used as the resultant coolant load.

## 3. Results

The contact pressure on the interface plays a key role in the GTRFW problems. When the local contact pressure is low, the support is not sufficient and the slip would occur once the fuel rod is subjected to a tangential load. When the local contact pressure is high, a small amount of slip would lead to high work rate, leading to quick wear growth. Figure 2 shows the contact pressure under different interferences. The initial contact contour is relatively small, particularily when the interference is small. Due to the growth of creep and wear, this contour is expected to grow over time. The contact pressure near the edge of the contact is significantly higher than the interior area. This is due to the stress concentration at the contact edge. The spacer grid is manufactured from stamping sheet metals, which creates sharp corners of the springs. These high contact pressure would cause high wear rate.

The contact slip is also an important factor in the GTRFW problems and it is closely related to the interference. Figure 3 shows the dependence of the slip distance on the interference. An axial displacement of 0.1 mm is applied to the fuel rod. When the interference is small, gross slip is noticed across the contact interface. As the interference increase, partial slip is observed. That is quite reasonable. Under a small interference, the preload is small too, leading to a relatively small static friction force. So the tangential load would easily overcome the static friction force and cause gross slip. As the interference increases, the tangential load becomes insufficient to cause slip everywhere, and the partial slip occurs at the contact edge.

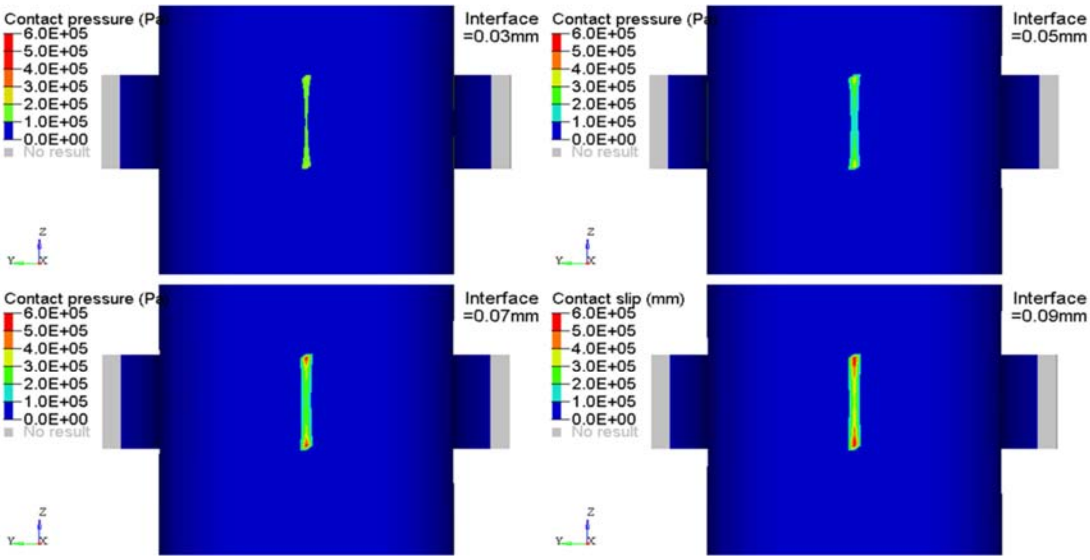


*Figure 2. Initial contact pressure on the grid to rod interface under different interferences. The initial contact contour is relatively small and stress concentration is noticed at the contact edge.*

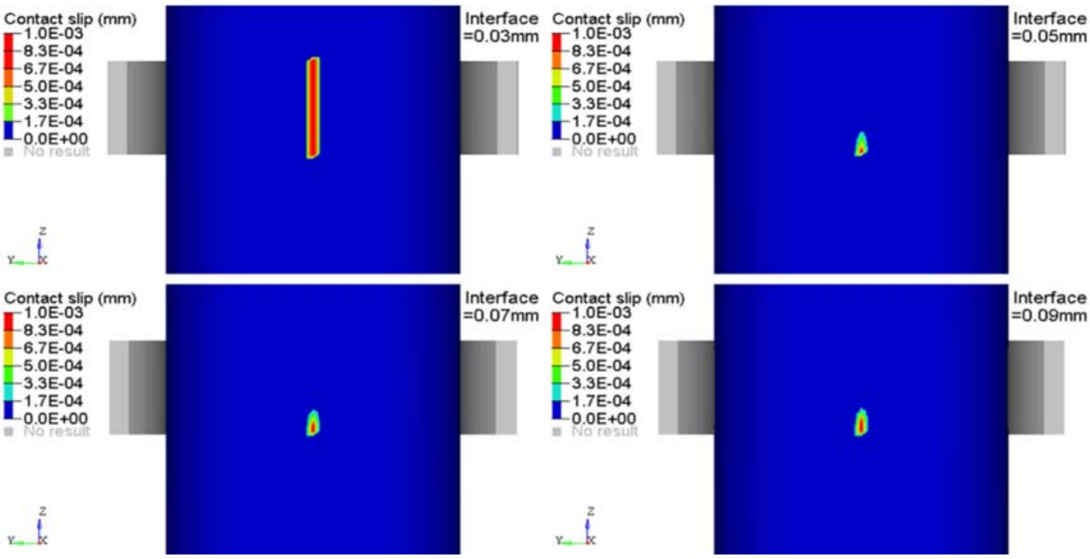


*Figure 3. Slip distance under different interference. Partial slip is noticed under large interference and full slip is noticed under small interference.*

Figure 4 shows the pulling force needed to cause gross slip on the contact interface under a friction coefficient of 0.1. The force is basically linearly dependent on interference as the model is in elastic domain. For a given interference, if the pulling force is less than the critical value, the contact interference would have partial slip or full stick condition. The partial slip wear on the grid to rod interface has been observed both numerically by Hu et al [22-24, 43, 44] and experimentally by Kim et al [34, 35, 37]. Significant efforts have been made by Hu et al. to understand the initiation and propagation of partial slip wear. They found that the wear usually initiates from the contact edge and eventually propagates to the entire interface. Those findings well explains the root mechanism of the GTRFW initiation.

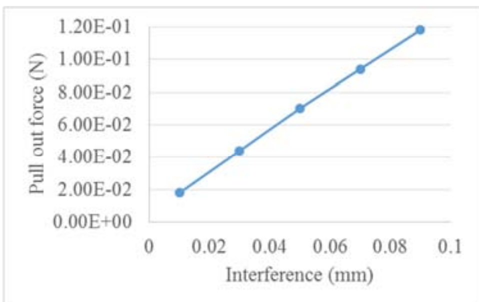


*Figure 4. Pulling out force increases linearly with the interference.*

# 4. Conclusions

Understanding the mechanism of GTFW is critical for predicting the fuel leak risk and optimizing the design of next generation PWR plants. In this study, a 3 D FEA model has been set up to analyze the initiation of GTFW. It is observed that the stress level around the edge of grid to rod interface is usually higher due to the stress concentration and the partial wear usually initiates from there. That would lead to a higher wear rate and the contact at those edges should be avoided. This observation is consistent with experimental observations and theoretical studies.

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