ADVANCED NUCLEAR FUEL DEVELOPMENT AND FUEL ROD FRETTING WEAR EVALUATION

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1. Introduction

The fretting wear of nuclear fuel rods in PWR reactors has been a long-standing concern for nuclear fuel designers, because of its impact on the economical and clean operation of nuclear fuel assemblies. The fuel rod fretting wear remains a continuous challenge for the designer because the design envelope pushes towards longer cycle lengths and higher burnup. KNFC has recently completed the development of the advanced 17x17 ACE7^{TM} and 16x16 ACE7^{TM} fuel for the Westinghouse type nuclear plants respectively. All of these advanced fuel design features include mixing vane spacer grids to increase thermal performance, advanced high burnup materials to enable high-duty, high burnup fuel management, and wide fuel cladding contact geometry for superior fretting wear performance. In this paper discussed various fretting wear evaluation methodology during the new fuel assembly development stage before in reactor commercial operations with the various test results.

2. Methods and Results

In this section some of the techniques used to evaluation methods and models of grid to fuel rod fretting wear are described.

2.1 Modeling and Modal Analysis of Cell

At the early stage of development the ACE7^{TM} advanced nuclear fuel assembly, various spring, dimple & fuel support concept designs were developed. To review the fretting wear characteristics and performance the 3-Dimensional grid modeling and modal analysis were conducted such as the natuaral frequency and mode shapes of the proposed concepts.(see fig. 1.)

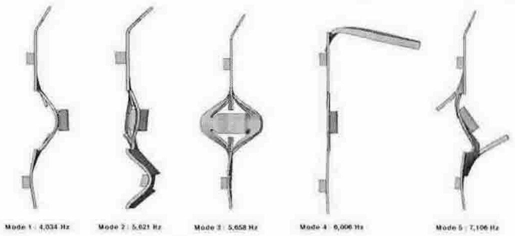

Figure 1. Grid Cell Modal Analysis

2.2 Wear Volume – Wear depth Evaluation

The maximum fuel rod cladding thickness are limited because of the thermal conductivity enhancement and the neutron absorption reduction, so the shallow wear depth is preferable at same wear volume aspect of fretting wear failure standpoint. The various spring and dimple concept designs were evaluated from 3-Dimensional CAD modeling to evaluate fretting characteristics. (see fig. 2.)

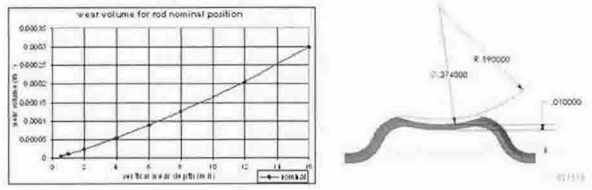

Figure 2. Fuel Rod Wear Volume-wear depth

2.3 Cell Wear test

To evaluate the advanced nuclear fuel assembly (ACE7^{TM})support system, the spring and dimple with fuel rod test sections were fabricated as fig.3 and conducted cell wear test. The wear volume and wear depth were compared at controlled work rate. And the wear coefficient were compared with various grid support designs against to the field fretting wear experienced grid design. Both 17x17 and 16x16 ACE7^{TM} designs shows excellent fretting wear behabior contrast to existing grid designs such as V5H.

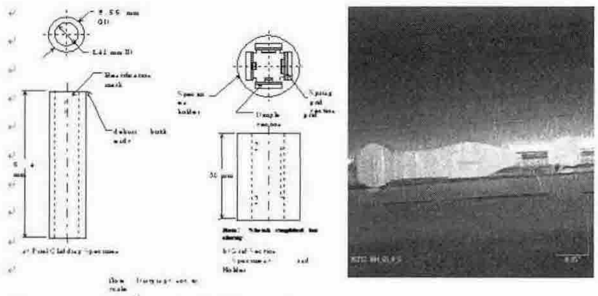

Figure 3. Grid Cell Wear Test

2.4 5x5 High Frequency Vibration Test

The various grid designs 5x5 test sections were fabricated for high frequency grid strap vibration test including ACE7^{TM} advanced nuclear fuel grid design at early development stage. The test were conducted at room temperature at various flow rate, the results are shown at fig. 4. As shown fig.4, V5H grid design shows relatively high vibration amplitude compared to other grid designs.

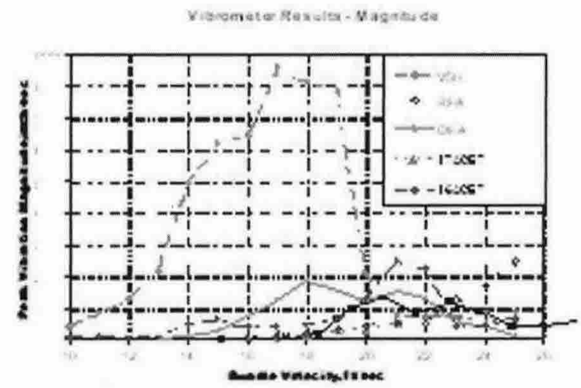

Figure 4. High Frequency Vibration Test

2.5 Modal Analysis and Fuel Assembly Vibration Test

The fuel rod and fuel assembly finite element models were built to analyze the mode shape and natural frequency of fuel rod and fuel assembly. The fuel assembly and fuel rod vibration test were conducted from low flow rate to very high flow rate. I recommend the simplified fretting wear model (following fig. 5 model) for the evaluation of fretting wear characteristics using to the vibration amplitude and frequency at reactor operating flow rate of assembly vibration test. The assembly vibration characteristic is the dominant factor of fretting wear failure mechanism among various characteristics.

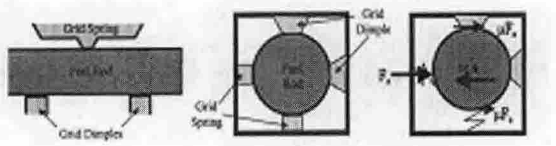

Figure 5. Simplified Fuel Rod & Grid Support Model for Fuel Assembly Vibration

2.6 Fretting Wear Evaluation

To evaluate the fretting wear characteristics of the advanced nuclear fuel design at the actual reactor operating conditions, long-term fuel assembly vibration test be recommened at high temperature and various flow conditions. The fuel rod to grid gap size were pre-set to conservativelly simulate at EOL operating conditions at this vibration test.

After the long term wear test, the fuel rods were retracted from the test assembly, and measured wear scar(volume and wear depth) of each spring and dimple contacted location of each grid elevation. From this wear scar data the fuel rod fretting wear failue date and quantity were estimated a long with previously evaluated wear volume and wear depth evaluation model. The results are shown as fig. 6.

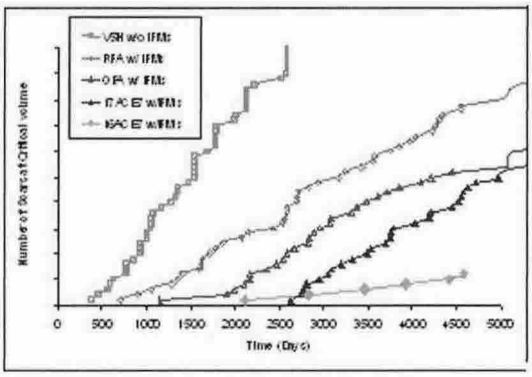

Figure 6. Fuel rod fretting wear evaluation results from long term fuel assembly wear test.

3. Conclusion

The advanced fuel designs are expected to be very excellent fretting behavior at operation conditions from the recommended evaluation methodology as shown above figure. From experience of this new fuel development projects and the various fretting wear evaluation methodology, I propose the followings be considered when develop new fuel grid assembly design to prevent fretting wear failure.

- Hydraulic Balance of Grid design
- Wide Contact Area of Fuel Rod Support System
- Optimized Spring Design(Elastic Deflection and Stiffness)
- Fuel Assembly Vibration Test and Long Term Wear Test
- Fretting Wear Evaluation (Recommended methodology)

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