Variation of Contact Conditions in 1x1 Unit Cell During Fretting of Nuclear Fuel Rod

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1. Introduction

In order to evaluate the fretting wear behavior, a work-rate model was proposed [1] and this model is widely applied to the estimation of the life time in relatively slender structures of nuclear power plants. The work-rate is used to normalize the wear rate and define as the rate of energy being dissipated at the contact as follows;

$$\dot{V} = K \cdot \dot{W} \qquad (1)$$

$$\dot{W} = \frac{1}{t}\int F \cdot dS \qquad (2)$$

where, $\dot{V}$ is wear rate, K is wear coefficient of the work-rate model and $\dot{W}$ is work-rate. However, it is well known that the wear coefficient K is not constant and it depends on the applied force, relative slip displacement, material characteristics, test environment, etc [2]. With increasing number of cycles in the fretting tests, the contact condition also changed due to the contact area variation, generation of wear debris, wear depth increase, etc. In this study, fretting wear tests were performed by using nuclear fuel rod against spacer grid spring/dimple to evaluate the variation of applied work-rate during fretting wear tests.

2. Methods

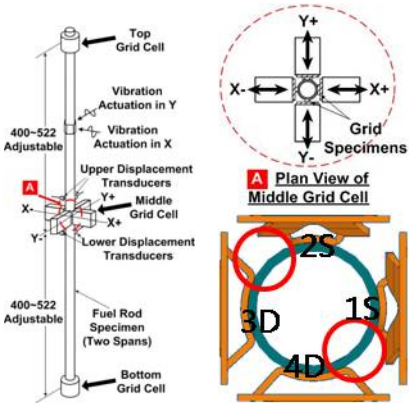

Fig. 1. Schematic views of fretting test method and 1x1 unit cell.

2.1 Specimen and Test Condition

A commercial nuclear fuel rod specimen with 870 mm of the length were prepared and equipped to vibrated jigs crossing at right angles. The center of upper span were actuated to a circular motion with ±300 μm of diameter and 29 Hz of frequency as shown in Fig. 1. A gap between fuel rod and each spring/dimple was set to 0.1 mm. In this study, a commercial mid grid spring/dimple specimen was used. Fretting wear tests was performed at high temperature high pressure (HTHP) distilled water condition (i.e. 320℃, 15 MPa). A detailed description of the fretting test facility can be found in a previous study [3]

2.2 Measurement of Contact Behavior

The exerted impact loads (i.e. gap condition) and relative displacements between fuel rod and spring/dimple specimen should be measured in order to evaluate an applied work-rate. Four load cells for HTHP condition were installed and connected to spring and dimple jig. Also, displacement sensors for HTHP condition (KAMAN) was quipped to upper and lower region of the center of fuel rod specimen, that was enabled to monitor the rod vibration behavior in an real-time basis.

2.3 Evaluation of Work-rate

During the fretting wear tests, impact loads are periodically measured and applied load per second are calculated by integrating the closed area on load-time graph. Contact displacement also calculated by using KAMAN signal and vibration frequency.

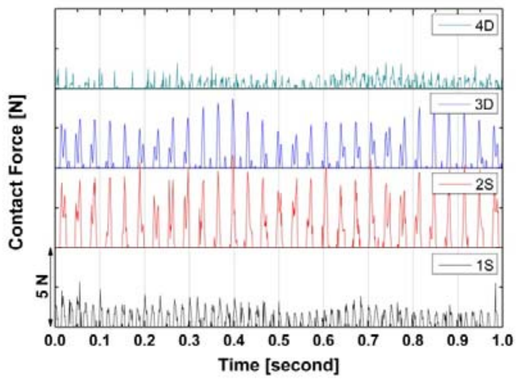

Fig. 2. Typical results of contact force variation at 1x1 unit cell.

3. Results and Discussion

3.1 Variation of Impact Load and Contact Time

Fig. 2 shows the measurement result of the contact force at each load cell. The maximum contact force and contact duration were varied with time. Based on the similar behavior of the peak force and contact time at 2S and 3D specimen, it is apparent that the fuel rod was simultaneously contacted with relatively large contact force compared with 1S and 4D. The numbers of contact and its contact duration are decreased and increased at higher peak loads, each respectively. This irregular contact could be confirmed by analyzing number of contacts at 1S and 4D, which has larger number of contacts compared with the operating frequency (i.e. 29Hz). So, actual contact behavior of the fuel rod specimen at center region was expected to have a bended oval or oblique motion even though the rod specimen has a circular motion. The impacting force difference at each spring/dimple specimen is that the additional impact force due to reaction force at the 2S and 3D specimen was exerted on the 1S and 4D specimen and consequently, their amounts were considerable decreased.

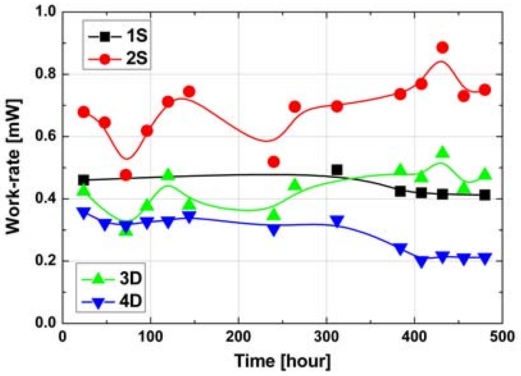

Fig. 3. Variation of work-rate during the fretting wear tests.

3.2 Variation of Work-rate

With increasing number of fretting cycles, applied work-rates at each contact region were calculated and their results are shown in Fig. 3. As expected, work-rate is not constant during the fretting wear tests and this is because the contact conditions are continuously changed. If fuel rod at contact region has a regular motion with a circular shape, sliding wear was more dominant rather than impacting wear. As shown in Fig. 1, the corner regions between spring and dimple specimen were regarded as obstacles against rod motion when the fuel rod was vibrated with a circular motion. This seems to result in irregular rod motions at the contact region. So, it is proposed that the geometrical parameter at the corner of 1x1 unit cell has a strong influence on the rod motion at contact regions, which was linked directly with the wear behavior. Consequently, the stiffness of spring/dimple, gap enlargement due to the wear depth increase, error of initial gap condition and rod mass play important roles in the work-rate at each contact region. Further studies will be focused on the various grid spring/dimple shape effect on the rod motion at the contact region.

4. Conclusions

The fretting wear test at the high temperature and pressure condition is performed by using a nuclear fuel rod and grid spring/dimple (1x1 unit cell) and the variation of work-rates during fretting wear tests are evaluated. The reaction force at spring/dimple could be generated an additional impact force. It is proposed that the geometrical parameter at the corner of 1x1 unit cell has a strong influence on the rod motion at contact regions, which was linked directly with the wear behavior.

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