FRETTING WEAR OF A SPRING SUPPORTED TUBE SUBJECTED TO TRANSVERSE VIBRATION

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Studied is fretting wear behaviour of transversely vibrating tube which is supported by springs and dimples. This simulates the fuel rod fretting due to flow-induced vibration in a nuclear reactor. The contact between spacer grid springs and fuel cladding tubes are brought into focus in this paper. From the mechanical viewpoint, a concave contact shape of spring is considered to perform a wider distribution of the contact stress. Sliding/impacting experiments are conducted in air at room temperature with the conditions of positive contact force and gap existence to accommodate the mechanical condition between the fuel rod and the grid spring during reactor operation. It is found that wear region is separated and wear volume becomes larger as the supporting condition becomes poorer. Spring and dimple cause similar wear.

Keywords : Fretting Wear, Sliding/Impacting, Concave Contour, Supporting Condition

1. INTRODUCTION

In light water reactor (LWR) fuel, a fuel rod has very high slenderness ratio, so a mechanical structure is necessary to support the rod. Spacer grid assembly, composed of crossed thin straps having protruded springs and dimples that contact the rod, is in charge of the function of support. During the reactor operation, the fuel rods vibrate due to coolant flow. Although it is pursued to maintain a sound support by the springs (and dimples) during the fuel life, the supporting condition becomes degraded due to the irradiation and thermal effects on the grid and the rod material.

The vibration amplitude becomes higher if the supporting condition is degraded, which can cause severe wear of the fuel rod. If the rod is perforated due to the wear, fission gas inside the rod comes out to the coolant, which results in the contamination of the coolant. It is strictly regulated in the power plant not only from safety concern but also from economical aspect. In this paper, fretting wear of a transversely vibrating tube is studied experimentally. The purpose of the present research is to investigate and understand the wear characteristic and severity on the fuel fretting problem, which are influenced by the contact shape and supporting condition.

2. EXPERIMENT

Fretting wear tester is particularly designed for the present experiment whose details have been already published elsewhere [1]. It uses lever system to convert the rotation of the motor to linear reciprocating motion. A spring specimen has a spring on one side and two dimples on the other side. Both spring and dimple have concave contour that surrounds the tube circumferentially. In axial direction, the spring (dimple as well) has a flat contour with chamfered edges. The distance between each chamfer starting point is 4.1 ± 0.02 mm. The alignment and contact configuration of the spring and tube specimens are illustrated in Fig. 1. The distance between each cell, which the tube is in contact with, is set 522 mm, the actual distance between the adjacent spacer grids.

Contacting force of 5 N, 0 N and gap of 0.1 mm are applied (termed L, J and G condition in order). The material of the tube and the spring specimen is the same, zirconium alloy, whose mechanical and chemical properties are given in Table 1. The diameter and the thickness of the tube specimen are 9.5 mm and 0.6 mm, respectively. Springs and dimples are fabricated by pressing the strip of 0.46 mm. The average surface roughness (R_a) of the tube and the spring specimen is 0.76 μm and 0.67 μm, respectively. The experiment is performed under laboratory environment. The frequency of tube oscillation is set 30 Hz with the range being 0.7 mm at the center of the tube specimen assembly. Each experiment finishes when the oscillation cycle reaches 10^6. Dimension, depth and volume of every wear scar on the tubes are examined and analysed. Wear volume is evaluated using a particularly developed program [2]. The experiment is repeated three times for each condition, and the volume is averaged.

Table 1. Properties of the specimen material

Mechanical properties (at room temperature)			
Tensile strength	Yield strength (0.2% offset)	Elastic Modulus	Poisson's Ratio
470 MPa	315 MPa	136.6 GPa	0.294

Chemical composition (wt. %)						
Sn	Fe	Cr	O	C	Si	Zr
1.28	0.22	0.12	0.114	0.013	0.010	base

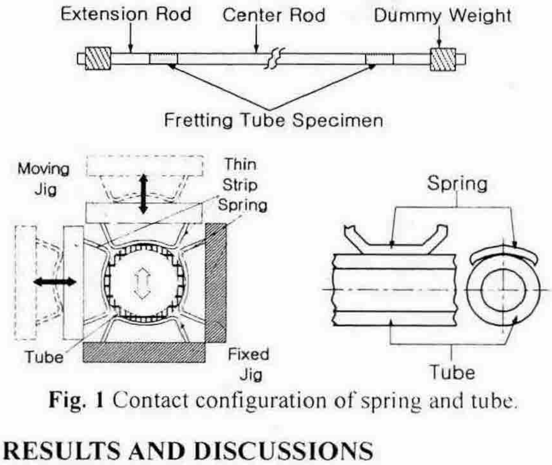

Fig. 1 Contact configuration of spring and tube.

3. RESULTS AND DISCUSSIONS

3.1 Wear scar view

Wear region is mostly separated to occur at contact edges as shown in Fig. 2. It is *partly* due to the tube motion during oscillation; like a seesaw in the plane of tube oscillation, while like an oar in the perpendicular plane of that. Also, it implies the slip displacement on the contact is not enough to reveal gross sliding wear under the given contact force. Another feature of the wear scar is a triangular shape such that wear scar width is larger at the contact edges and becomes narrower as it goes towards the center of the contact. As the condition varies from L, J and G, the width and length of the scar grow.

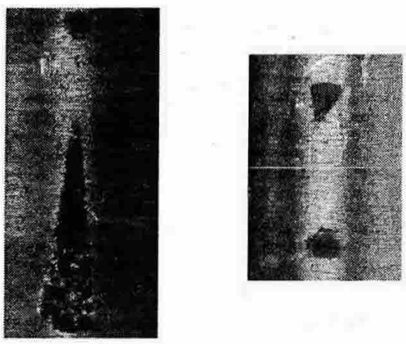

Fig. 2 Typical view of wear scar on tube (left: spring contact, right: dimple contact).

3.2 Supporting condition and wear volume variation

Fig. 3 shows the influence of supporting condition on wear volume. Wear volume at each contact (between tube and 4 springs and 8 dimples) is summed and then averaged by the number of experiments. As anticipated from the scar view, wear volume increases as the support loosens. Therefore, we can conclude that fuel fretting wear is restrained if the fuel rod is supported with positive force as long as the present spring shape is used.

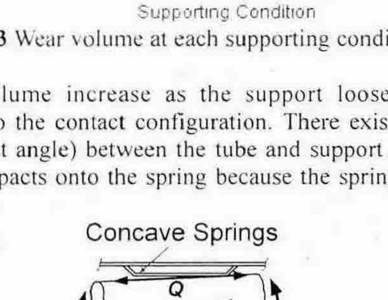

Fig. 3 Wear volume at each supporting condition.

The volume increase as the support loosens is also attributed to the contact configuration. There exists an angle (say, contact angle) between the tube and support surfaces as the tube impacts onto the spring because the spring has a flat contour in axial direction and the tube oscillates as a seesaw (Fig. 4). In this case, the impact of tube onto the chamfer starting point may result in severe plowing of the tube surface. The plowing is less severe in the case of positive contact. The triangular wear shape is also explained from the seesaw motion. However, different mechanism other than plowing is necessary to apply to analyze the wear by a convex spring (such as plastic flow) [3].

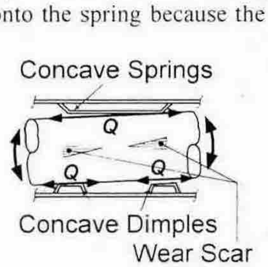

Fig. 4 Contact configuration at the time of impacting.

3.3 Difference in wear by spring and dimple

Presently, the dimple length is about a half of the spring length, so the wear difference between the spring and dimple contacts can be investigated by comparing the wear volumes induced by them. It may show the influence of the stiffness of support on wear because the dimple is much stiffer than the spring. Fig. 5 gives total wear volume obtained from the three repetitive experiments at each condition. Wear volume in the case of the contact with dimple is mostly greater except in the J condition. In overall, 63% of total volume is attributed to the dimple contact. However, if the data scatter, generally found in the wear experiment, is accommodated, it is difficult to say the dimple is more sensitive in wear than spring. Rather, it is regarded the spring and the dimple cause similar wear. This result may alter if the contact configuration is changed.

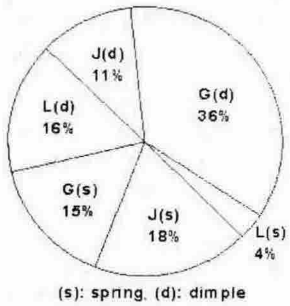

Fig. 5 Difference in wear volume caused by spring and dimple contacts at each supporting condition.

4. CONCLUSIONS

In the case of the contact with concave springs and dimples against a vibrating tube, supporting condition is a sensitive parameter in tube wear. Less support results in larger wear. It is highly required to avoid the gap between the tube and the support to restrain wear. The wear starts from the contact edges and expands inwards. This phenomenon and the severe wear in the case of gap existence can be explained by the tube motion and the support geometry by which wear mechanism is affected. The difference in wear volume induced by dimples and springs is not discriminating.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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