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Fretting Wear Analysis under Various Loading Combinations

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1. Introduction

Finite element analysis of the fretting wear on the secondary side of the steam generator, caused by flow induced vibration (FIV), was investigated in this study. Two-dimensional finite element models with cylinder-plate contact were adopted. Various combinations of loads and displacements are applied to explain the different fretting wear mechanisms, such as stick only, stick-slip, and gross slip regions. The algorithms are developed and programmed in connection with ABAQUS to calculate wear depth and to modify finite element mesh at each cycle. As a result, regions for each fretting wear mechanism are found and fretting wear map is constructed, which can be used as a reference or criterion for fretting wear experiments.

2. Finite Element Analysis

2.1 Work Rate Model

The work rate model related the time rate change in the amount of dissipated energy by fretting wear with the wear rate can be described as follows.

$$\dot{W} = \frac{1}{t}\int F_n \cdot ds \tag{1}$$

$$\dot{V} = K\dot{W} \tag{2}$$

In the present study, the recent trend of using the wear constant, *K*, defined in the wear rate model was used to calculate the amount of fretting wear.

2.2 Finite Element Analysis

In order to simulate the various contact conditions under different loading combinations, cylinder-plate contact model was considered as shown in Fig. 1. The diameter of the cylinder is 12 mm and the plate is 10 mm thick. The finite element model was assumed to be in plane strain condition and a fine mesh with the minimum size of 10μm was generated around the contact region.

Four different loading combinations were considered in this study as shown in Table 1. Case 1 was thought to be a fretting wear analysis in the typical stick-slip region. Case 2 was executed by increasing the amount of displacement amplitude thereafter, and Case 3 by decreasing the applied load. Finally, fretting wear analysis of Case 4 was performed, which was thought to be in the gross slip region.

Table 1 Loading combination of each case

	Normal Load (N)	Displacement (μm)
case 1	1200	2.5
case 2	1200	10
case 3	600	2.5
case 4	185	10

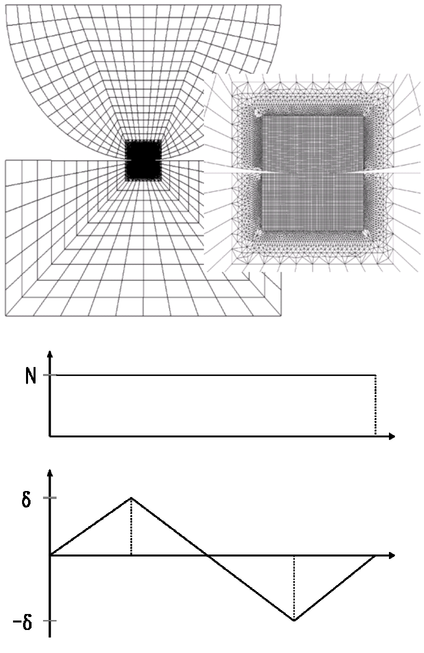

Fig. 1 Finite element modeling and loading history of the cylinder-plate contact

From the work rate model, the wear depth was defined as follows:

$$\text{wear depth} \equiv K \cdot u_t \cdot \sigma_n \tag{3}$$

where K is the wear constant, u_t is the relative slip defined as the difference between tangential displacements, and σ_n is the normal contact stress. In the first cycle, after calculating the stress and displacement fields of each node and element by two-dimensional elastic finite element analysis, the wear depth was computed according to the work rate model. After the first cycle, the finite element mesh was moved a distance equal to the amount of the wear depth and was therefore ready for the next cycle, and so forth.

In order to reduce the computing time required for the analysis, the concept of a control parameter s was introduced, which scaled up the wear constant and scaled down the actual number of cycles in the analysis. The effective wear constant K_e ($\equiv K \cdot s$) and effective number of analysis cycles N_e ($\equiv N \cdot s$) were defined as the values of the wear constant and number of analysis cycles increased by s times, respectively. Although the actual wear constant was $K = 1.0 \times 10^{-11}$ Pa^{-1}, the effective wear constant K_e ($\equiv K \cdot s$) was used in the actual computations over the actual numbers of analysis cycles $N(\equiv \frac{N_e}{s})$, which found to have the same effect as analyzing the effective number of cycles N_e. To demonstrate the feasibility of introducing the control parameter s, the results of analyses for different values of s, such as 10, 20, and 50, are compared, which shows unstable results for too big s (s = 50) values. But similar results were obtained for s=10, 20; therefore, it is found that using this methods (taking s = 20) provides a great advantage of reducing the analysis time required to obtain a reasonable solution.

3. Results and Discussions

The results of the analyses in each case were plotted and interpreted until the number of cycles N = 1800. And also among the results, normal contact pressures and the distributions of wear depths are compared with the existing solutions by Leen [5]. In Case 1 (stick- slip), maximum normal contact pressures are developed at each of the boundary of stick and slip region.

By increasing the amount of displacement (Case 2), normal contact pressure converges to a constant value as the number of cycle increases. The result could be interpreted as the increase of extent of contact region with the number of cycles, which is the typical pattern of fretting wear in gross slip region.

By decreasing the applied load (Case 3), the amount of relative slip and the extent of contact region increase as the number of cycle increases. The result could also be explained as the transition from stick-slip region to gross slip region by decreasing the amount of applied load.

In order to find out the fretting wear conditions with the variations of loads and displacement amplitudes, aforementioned finite element analyses were executed under three different displacement conditions (1μm, 2.5μm, 10μm). Consequently, fretting wear map as in Fig. 2 is constructed which can classify stick, stick-slip, and gross slip regions with the combination of applied load and displacement amplitude. In this analysis, when the percentage of the length of no relative slip region in whole contact region is above 80%, the region is assumed to be the stick region. When the percentage reduces to zero, gross slip region is assumed and in-between as stick-slip region.

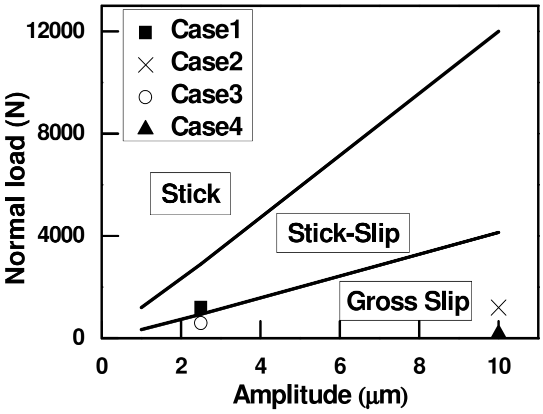

Fig. 2 Fretting wear map

4. Conclusions

Finite element analyses of fretting wear with cylinder plate contact under various loading conditions are performed and the following conclusions are made.

- In order to reduce the computing time, a control parameter is introduced and verified to reduce the computation time.
- By increasing the amount of displacement or by decreasing the load, transition from stick-slip to gross slip was found in fretting wear mechanism.
- Fretting wear map is constructed which can classify stick, stick-slip, and gross slip regions along with the various combinations of applied load and displacement amplitude.
- Fretting wear map can be used as a reference for fretting wear experiments

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