Torsional Fretting Wear of Annular Flat-Flat Contact Interface Under Different Road Clamping Force and Torque

Zhenfa Wang, Lihua Yang*, Kun Xie and Yong Huang

ABSTRACT

For the rod fastening combined rotor in some heavy-duty gas turbine, the annular flat-flat contact interfaces are usually used between disks to transmit the torque. In this paper, a contact model of two disks assembled by 12 circumferential preload tie rods is established to study the fretting wear behavior of the annular contact interfaces under variable torque and different preload of tie rods. The changes of contact stress distribution, slide distance and wear depth of the annular contact interface with torque and rod preload are obtained. The results show that the wear depth is increasing with the growth of torque and rod preload.1

INTRODUCTION

In most advanced heavy-duty gas turbine, the rod fastening combined rotor is used in which the annular flat-flat contact interfaces are applied to transmit the torque and force. In general, these interfaces are working under the condition of variable amplitude cyclic loads which will result in fretting wear of contact interfaces.

Lihua Yang. State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an, Shanxi 710049, China
Lihua Yang. Shanxi Key Laboratory of Environment and Control for Flight Vehicle, Xi'an, Shanxi 710049, China
Zhenfa Wang, Lihua Yang, Kun Xie. School of Aerospace, Xi'an Jiaotong University, Xi'an, Shanxi 710049
Yong Huang. The 404 Company Limited. CNNC (China National Nuclear Corporation), Jiayuguan, Gansu, China, 735100
*Corresponding author: Lihua Yang, email: yanglihua_2@126.com
Fretting wear is a king of surface degradation which usually results in the material removal because of small amplitude vibration between the contact interfaces. It is the most universal damage form in engineering. Bases on the relative moving direction, the fretting wear is divided into four modes of radial, tangential, rotational, and torsional.

In order to investigate the influence factors of fretting, some simplified models of fretting device were used, such as flat-flat contact model, cylinder-flat contact model and spherical-flat contact model. Currently, some scholars have studied the fretting behavior of annular flat-flat contact interfaces under different conditions. Hintikka [1] established a fretting test rig of annular flat-flat contact to study the fretting behavior under different pressures and sliding amplitudes. Po Zhang et al[2] studied the torsional fretting wear of the fan-shaped flat-circle flat contact, and obtained the relationship of friction torque and angular displacement. SB Leen et al [3] obtained the SWT(Smith–Watson–Topper) parameter distribution of different fretting regions and predicted the fretting fatigue life. Teng Zhang [4] established a two-dimensional punch/flat finite element contact model, and obtained the evolution law of wear depth in different fretting regions under different cycle times. Arnaud [5] predicted the wear scars at different cycle times based on the Archard model and predicted the fretting crack generation using SWT parameters.

In rotor of heavy-duty gas turbine, there are a large number of annular flat-flat contact interfaces. Torsional fretting wear often occurs in these structures. Therefore, the purpose of this paper is to study the fretting behavior of the annular flat-flat contact interfaces under variable torque and rod preload.

**FINITE ELEMENT MODEL**

A three-dimensional assembly model of two disks fastened by 12 tie rods is established in ABAQUS, and 12 circumferential tie rods are numbered, as shown in Figure 1(a). Considering that the establishment of 12 solid rods will make the model more complex and result in difficulty in convergence. Therefore, a simplified model is adopted in which the rods are removed and only apply the preload of rods in the location of rod holes on the disk. Here the preload of rods is the normal force applied on the assembled model. The detailed mesh model is given in Figure 1(b). The isotropic Coulomb friction model is built by the penalty function method with the friction coefficient $\mu = 0.4$. In order to simulate the fretting behavior of the annular contact interfaces under the variable amplitude cyclic torque, the bottom surface of disk b is set to a completely fixed constraint and the torque $T$ is applied to the upper surface of disk a.
Figure 1. FE model(a) assembly model under rod preload (b) Mesh details of FE model (c) sector area with a central angle of 30°.

<table>
<thead>
<tr>
<th>Load parameter</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>preload of each rod F(N)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>mean torque T(N-mm)</td>
<td>1000</td>
<td>1500</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>

For each set of load, the preload of rods is constant. Firstly, torque is linearly applied from zero to $T_{mean}$. So a full cycle of torque is composed of four steps: loading torque from $T_{mean}$ to $T_{max}$, unloading to $T_{mean}$, continuously unloading to $T_{min}$, returning to $T_{mean}$. In each cycle, 10 loading increments are used for the application of torque. $T_{max}$ is 1.05% of $T_{mean}$ and $T_{min}$ is 95% of $T_{mean}$.

TABLE I shows six different sets of preload and torque parameters applied to study the torsional fretting wear of the annular flat-flat contact interfaces.

TABLE I. DIFFERENT LOAD PARAMETERS.

In order to study the variation law of the stress distribution in the annular flat under different preload and torque, rod 1 is taken as the center to intercept a fan-shaped annular flat area with angle of 30° shown in Figure 1(c). The $\theta$ direction is in the circumferential direction and the $r$ direction is in radial direction. The inner radius is $r_i = 361 mm$ and the outer radius is $r_o = 391 mm$. The nodes on the inner radius circle are taken as the feature nodes to present the fretting wear behavior. According to the existing literature [6], for a load cycle including $m$ loading increments, the total wear depth at the node $n$ is the sum of the wear depths at all loading increments in a load cycle ($i = 1, 2, 3, \ldots, m$).

$$\Delta h_n = \sum_{i=1}^{m} \Delta h_n^i = \sum_{i=1}^{m} k_l \cdot p_n \cdot \Delta s_n^i$$ (1)

Where $p_n$ and $\Delta s_n^i$ are the contact pressure and increment of relative slip at node $n$ for a given loading increment, respectively, $k_l$ is the local wear coefficient.
Based on Eq. (1), the wear depth of z load cycles at the node n is the sum of the wear depths of each load cycle.

**NUMERICAL RESULTS**

![Contact stress distribution of disk a for load parameter of case 1.](image)

Figure 2. Contact stress distribution of disk a for load parameter of case 1.

As shown in Figure 3, the contact stress exhibits a downward trend with the increase of radius \( r \). Near the region with bigger radius \( r \), the contact stress is zero, because the preload is small which results in that two disks can't contact entirely in this region. So the preload should be increased to ensure the complete contact. For certain radius \( r \), the contact stress is symmetrically distributed about the center and the contact stress is maximum at the center.

**Effect of Torque On Fretting Wear**

Figure. 3 shows the effects of torque on fretting wear. It can be seen that the torque has little effect on the contact stress when the rod preload is constant. And the maximum shear stress appears in the region near the rod hole. The cumulative slip is smaller in the region with large contact stress than those with small contact stress. The increase of torque causes the rise of cumulative slip distance because the shear stress of contact surface increases. The fretting wear depth is obtained from the equation (1). The increase of the torque will increase the wear of the contact interface and the wear will be more serious at the place near the rod.
Effects of Rod Preload on Fretting Wear

Fig. 4 illustrates the effects of rod preload on fretting wear. It indicates that with the increase of the preload, the contact stress and wear depth increase, while the cumulative slip distance decreases. The contact stress and wear depth near the rod have the larger values, while the cumulative slip distance has smaller values.

**CONCLUSIONS**

In this paper, a three-dimensional simplified finite element model of two disks assembled by 12 fastening rods is established to study the torsional fretting wear of the annual flat-flat contact interfaces used in heavy-duty gas turbine. The following conclusions can be drawn:

1. The wear of the region near the rod is more serious than other regions.
2. With the increase of the torque, the shear stress of the annular plat will increase which aggravates the wear.
3. With the growth of preload, the contact stress of the contact surface will increase, which also lead to more serious wear.
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REFERENCES