FEM Simulation of Fretting Corrosion

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Wear on contact surfaces, called fretting corrosion, frequently occurs when connected machine elements are used under fluctuating load conditions. Fretting corrosion often causes abnormal vibration or reduction in fatigue strength, thus requiring close study in the initial design stage. This paper presents the FEM simulation method for fretting corrosion based on its generation mechanism. The simulation results of a wheel bearing were identical to the appearance of the actual fretting corrosion generated after a rolling bending fatigue test.

Key Words: rolling bearing, FEM, fretting, contact pressure

1. Introduction

In mounting rolling bearings to machines, the first item to be examined is fitting. How to set the fitting between the inner ring and the shaft, or the outer ring and the housing, is determined by considering the operating conditions of the bearing. Careful attention is required particularly under drastically fluctuating load conditions.

When relative sliding, due to repeated loading, occurs on each contact surface, wear phenomenon occurs on the contact surface. This phenomenon is generally called fretting corrosion.\(^1\)

When fretting occurs in machine elements where relative movement is restricted, clearance is generated, thereby causing abnormal machine vibration, abnormal noise, or reduction of fatigue strength, which may result in failure of machine elements.\(^2\) In product designing, it is important to pay attention to this point.

However, bench tests and the like were the only possible means to verify fretting as there was no effective method to study it theoretically.

This paper introduces a method to simulate the fretting using FEM analysis on the basis of its generation mechanism. A simulation example of fretting generated on the flanged surface of a hub unit is also presented here.

2. What is Fretting Corrosion?

2.1 Occurrence Mechanism of Fretting Corrosion

No sliding phenomenon occurs on the contact surface of connected machine elements or structures under static conditions. On the other hand, if fluctuating load is applied, relative sliding may occur from elastic deformation caused by difference in stiffness of composed parts. At the sliding position, wear particles are generated due to the repetition of sliding. Wear particles generated there are oxidized and changed harder, accelerating further wear. This kind of phenomenon is called fretting corrosion (or fretting wear). In this paper, fretting corrosion is expressed merely as fretting.

2.2 Example of Fretting and its Problems

Examples introduced here are not those including special problems, but are selected from those easy to generate fretting phenomenon.

Figure 1 shows the structure of a typical 1st generation front wheel bearing (DAC) for FF (front-wheel drive, front engine) cars. The bearing supports the radial load due to the vehicle weight and the axial load due to turning during actual running. In particular, when the lateral acceleration is large, the acting axial load at the tire contact point becomes large, and large moment is loaded on the bearing. Under these conditions, large fluctuating load occurs at the fitting surface between the rotating inner-ring and the hub shaft. This condition is susceptible to fretting occurrence.
3. FEM Simulation

Here introduces a case study on FEM simulation of the fretting generated on the flange surface of a wheel hub unit based on the fretting generation mechanism as previously described.

3.1 Concept for Simulation

Fretting progresses in accordance with the generation of wear particles due to repetition of relative sliding movement and the hardening of wear particles by oxidization. Generation of clearance is necessary for the oxidization of wear particles. Consequently, fretting is considered to occur on the position where the components keep contacting and separating alternately during operation. In other words, fretting will not occur where the components remain either contacted or separated.

Here, the zone where the components contact and separate during operation is defined as the fretting acting zone. The distribution of contact pressure in the fretting acting zone is termed the fretting contact pressure.

Figure 2 shows a typical example after a bench test for simulating actual vehicle conditions. Fretting generation is observed on both inner ring and shaft.

Recently, unitized bearings, i.e. hub units, are often applied for wheel bearings due to various advantages. Figure 3 shows the structure of typical hub unit for wheels.

Figure 4 shows a typical example after a bench test for simulating actual vehicle conditions. Fretting generation is observed on both inner ring and shaft.

Figure 5 shows a typical fretting appearance after the rotating bending fatigue test. The generation of fretting can be observed over quite a wide area of the flange surface.

Figure 6 shows a typical example after a bench test for simulating actual vehicle conditions. Fretting generation is observed on both inner ring and shaft.

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3.2 FEM Model

The distribution of fretting contact pressure between the flange surface of the hub unit and the brake disk can be obtained by the following calculation: ① Compute the distribution of contact pressure between the flange surface and the brake disk for each loading condition ② Within the contact pressure distribution zone, delete the sections where the contact situations do not change based on the change of the loading direction or magnitude.

The contact pressure distribution of the flange was computed using a general purpose FEM code with high contact analysis function. Spreadsheet software was used to extract the section where the contact pressure changed.

Figure 6 shows an example of the FEM mesh distribution. The computation model was composed of a hub unit, brake disk, wheel, hub bolts, nuts and other components. For the hub unit bearing, only the inner ring and shafts were selected for modeling. As to the wheel and brake disk, only the periphery of the contact section was selected for modeling considering the computation cost. A hub unit, brake disk and wheel were clumped with hub bolts and nuts. As to the constraint condition, fully constrained condition was adopted only for the wheel end surface.

Loading was converted to rolling element load distributions and was applied on each nodal point as the concentrated load. In addition, in order to simulate the load variation during one rotation of the wheel, the direction of radial load was varied in 20 different angles (in increments of 18°) as shown in Fig. 7.

3.3 FEM Analysis Result and Actual Fretting Appearance

Figure 8 shows the distribution of fretting contact pressure computed from FEM analysis. Also Fig. 9 shows the actual fretting appearance after a rotating bending test was conducted with the same loading conditions.

Compared with the actual fretting appearance, the distribution of fretting contact pressure computed by FEM analysis could closely simulate the actual fretting appearance since no fretting was observed immediately around the bolts or at the central sections of the flange between the bolts.

In order to use FEM analysis results at the design stage, it is necessary to extract parameters that can quantitatively evaluate the degree of fretting.

From the viewpoint of the generation mechanism of fretting, one of the parameters to be considered is the integrated workload in the fretting acting zone, which is caused by the friction force for one rotation of the wheel. This workload indicates the degree of mechanical action related to fretting. Theoretical estimation of fretting at the design stage may become possible if the relationship between this workload and abnormal vibration, abnormal noise and so on is investigated in advance.

However, fretting wear progresses with time and it should be pointed out that the progression of fretting cannot be simulated in this method.
4. Conclusion

This paper introduced the method of fretting simulation based on the fretting generation mechanism. As a result of applying this method to hub units, it was confirmed that the simulated appearance was almost identical to that of actual fretting.

Moreover, the FEM simulation technique of fretting introduced in this paper may be applied widely to other connected mechanical elements and structures used under fluctuating load conditions as well as hub units.

By utilizing this method at the design stage, it is thought to be possible to examine the abnormal vibration and noise created by fretting in advance.

Recently, CAE (Computer Aided Engineering) has been increasingly applied in development for reducing the development cost and shortening the development time. This case study is one of such attempts and it is our sincere desire to further advance the technical development to reduce the number of conventional tests using actual components.

References


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