Generation of inner ring creep is a serious problem in rolling bearings. When there is insufficient interference or excessive load is imposed on the inner ring, the inner ring rotates reverse to the direction of shaft rotation. This movement is called creep.

To clarify the precise generation mechanism of creep, examinations were made under relevant experimental conditions of "transition fit" and "interference fit."

This paper describes how these conditions affect the creeping phenomenon.

**Key Words:** creep, interference fit, transition fit, FEM

1. Introduction

When a rolling bearing is mounted on a rotating shaft with insufficient interference, or when it is subjected to excessive load, the problem of creep often occurs: the inner ring moves relative to the shaft in the direction opposite to shaft rotation.

Generally, two different mechanisms of creep occurrence are known in bearings mounted with interference. One is in the case of transition fit between the shaft and the inner ring, where the clearance may be developed between them due to deformation of these parts under radial load. If the shaft is rotated under such clearance condition, there will be a geometrical displacement of the inner ring relative to the shaft, or creep (Fig. 1). To prevent creep from developing based on this mechanism, at least the interference as defined in the equation (1) is required.

The other mechanism of creep takes place in case of interference fit. According to Imai^3, creep generates when the shearing stress generated on the fitting surfaces ($\tau(\theta)$) overcomes the frictional force due to the contact pressure toward the tangential direction ($\mu \sigma(\theta)$) in case a load is imposed (Fig. 2). The minimum required interference to prevent the creep based on this mechanism is obtained by the equation (2)^3.

In this paper, in addition to basic experiments concerning creep, further study into the above creep mechanisms was shown in detail using the three-dimensional finite element method analysis (FEM analysis). In particular, a mechanism in which an inner ring slides in accordance with rolling movement of rolling elements was discussed. In the near future, more correct estimation of creep phenomenon will be made possible based on these findings.
2. Measurement of Creep Triggering Load

2.1 Test Method

Figure 3 shows the schematic of the tester.

The shaft with a sample bearing press-fitted is assembled with the rotor shaft of the tester and rotated. Pure radial load is imposed with the loading jig attached to the bearing outer ring. And a spacer is fitted on the shaft to prevent the bearing from being displaced axially due to creep. This spacer is loose fitted on the shaft, with some axial clearance so as not to hinder the creep occurrence.

![Fig. 3 Schematic of testing device](image)

Test bearing specifications, shaft specifications and test conditions are summarized in Tables 1, 2 and 3, respectively.

**Table 1 Test bearing specifications**

<table>
<thead>
<tr>
<th>Items</th>
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<tbody>
<tr>
<td>Bearing No.</td>
<td>6208C3 (resin retainer)</td>
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<tr>
<td>ID × OD × Width</td>
<td>40 × 80 × 18</td>
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<tr>
<td>Basic dynamic load rating, kN</td>
<td>29.1</td>
</tr>
<tr>
<td>Basic static load rating, kN</td>
<td>17.8</td>
</tr>
<tr>
<td>Number of balls, pcs.</td>
<td>9</td>
</tr>
<tr>
<td>Material</td>
<td>SUJ2</td>
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<tr>
<td>Bore finish</td>
<td>Grinding (Ra = 0.4 ~ 0.5)</td>
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<tr>
<td>Bore roundness (minimum zone center)</td>
<td>1 ~ 2 μ m</td>
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**Table 2 Shaft specifications**

<table>
<thead>
<tr>
<th>Items</th>
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<tbody>
<tr>
<td>Shape</td>
<td>Hollow shaft (bore diameter 28)</td>
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<td></td>
<td>Solid shaft</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>40</td>
</tr>
<tr>
<td>Material</td>
<td>S45C</td>
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<tr>
<td>Outer diameter finish</td>
<td>Grinding (Ra = 0.3 ~ 0.4)</td>
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<tr>
<td>Outer diameter roundness (minimum zone center)</td>
<td>1 μ m</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>None</td>
</tr>
</tbody>
</table>

2.2 Creep Triggering Load

Results of creeping tests are shown in Fig. 4, where the horizontal axis represents the interference, and the vertical axis the radial load, and the radial load at which the inner ring started to move relative to the shaft (hereinafter referred to as creep triggering load) was plotted.

![Fig. 4 Creep test result](image)

As seen in Fig. 4,

1) with the interference around 10 μ m, the measured creep triggering load is somewhat greater than the value estimated by equations (1) and (2), whereas the values for hollow shaft with 30 μ m match well with the estimation by the equation (2).

2) in case of the hollow shaft with 50 μ m interference, the creep triggering load is somewhat lower than the estimated value by the equation (2), possibly due to the influence of shaft deflection, etc.

3) in case of the solid shaft, the load required to trigger creeping is higher than that with the hollow shaft. This is presumably due to higher contact pressure with the solid shaft.

Next, these test data in Fig. 4 were rearranged by changing the horizontal axis to represent the contact pressure as shown in Fig. 5. This figure reveals that the creep triggering load is virtually proportional to the surface pressure (except 50 μ m interference). Therefore, the creep triggering load is obviously almost liner to the surface pressure.
2.3 Degree of Creep

In Fig. 6, measurement results of the degree of creep (angular movement of the inner ring relative to the shaft) were shown when the load was continuously increased after initial creep occurrence.

1) As a whole, the degree of creep tends to increase in accordance with the increases of the load.
2) With the interference of around 10 $\mu$m, the degree of creep increases drastically with the load, while with the interference of 30 $\mu$m or more, the degree of creep increase is much more moderate.

3. Measurement of Inner Ring Sliding

In order to study the mechanism of creep generation, the location of sliding between the inner ring and the shaft was measured.

3.1 Test Method

The position at which sliding between the inner ring and the shaft occurred was measured while the inner ring was rotated slowly.

The test method is shown in Fig. 7.

An iron chip was fixed on the inner ring, while a displacement sensor 1 fixed on the shaft measured the movement of the iron chip, which shows the relative displacement between the inner ring and the shaft. At the same time, another displacement sensor 2 was attached to the iron chip to identify the relative position of the rolling elements.

Table 4 shows the test conditions.

<table>
<thead>
<tr>
<th>Items</th>
<th>Contents</th>
</tr>
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<tbody>
<tr>
<td>Inner ring – shaft</td>
<td>Hollow shaft</td>
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<tr>
<td>interference</td>
<td>10 $\mu$m target, 30 $\mu$m target</td>
</tr>
<tr>
<td>Radial load</td>
<td>20 kN, 30 kN, 40 kN</td>
</tr>
<tr>
<td>Rotation</td>
<td>Manual rotation</td>
</tr>
</tbody>
</table>

3.2 Position of Sliding

Test results for the interference of 10 $\mu$m and 27.5 $\mu$m are shown in Figs. 8 and 9, respectively. In each figure, the horizontal axis represents the angle of rotation, and the vertical axis the relative displacement angle between the inner ring and the shaft (displacement in the opposite direction of inner ring rotation is defined as positive value).
4.2 Result of FEM Analysis

FEM analysis was conducted for two levels of interference (10 μm and 30 μm). Figure 11 shows an example of distribution of contact pressure (σ) between the shaft and the inner ring in case of 30 μm interference and 30 kN radial load. Figure 12 shows the circumferential distribution of the shearing stress (τ) under the same conditions. Furthermore, since these three-dimensional figures are not clear enough, Figs. 13 and 14 are provided, respectively showing the circumferential distribution of contact pressure at the center of fitting surfaces and the distribution of shearing stress.

1) As seen in Figs. 11 and 13, in the loaded area (90°~270°), some peaks of the contact pressure appeared at the positions corresponding to the rolling element load. In the non-loaded area under the 90° position, the contact pressure showed low level, which was considered to be the surface pressure due to fit. In particular, for the 10 μm interference, the pressure was almost zero.

2) As shown in Figs. 12 and 14, shearing stress showed peaks at the positions slightly off the rolling element load.

4. Verification by Finite Element Method (FEM) Analysis

4.1 Model

Figure 10 shows the FEM model, which is the modeling of the shaft and the inner ring of the tester shown in Fig. 7. As with the load, the rolling element load was input as the contact pressure distribution.
Then, taking into account the following relationship that determines the triggering point of sliding between the inner ring and the shaft,

\[ s > l_r \]

where, \( l_r \) : Static coefficient of friction ...... Obtained by actual measurement by the method shown in Fig. 15.

The distribution of the sliding amount was calculated by inputting the \( l_r \) values into the FEM analysis. Figure 16 is the 3D graphic output of the circumferential distribution of sliding on the fitting surfaces between the inner ring and the shaft with the interference of 30 \( \mu \) m and the radial load of 30 kN. Figure 17 shows the 2D output of such sliding distribution.

1) From Figs. 16 and 17, rolling elements positioned near 180°, where load is rather large, showed the peak of sliding at the position tilted to the 0° side.

5. Discussion

FEM simulates the static equilibrium condition at a given moment. Therefore, the condition of fitting surfaces for FEM analysis as described in Section 4, is considered to change dynamically by the passing of rolling elements, which results in sliding of the inner ring as shown in the results in Section 3.

Also, from the test results in Section 3, it is necessary to consider the creep generation mechanism with the interference of around 10 \( \mu \) m as distinctly different from that with the interference of 30 \( \mu \) m. In other words, for around 10 \( \mu \) m interference, the creep generation mechanism by transition fit is predominant and, for around 30 \( \mu \) m interference, the creep generation mechanism by interference fit is predominant.
5.1 In Case of Transition Fit

From the measurement results in Fig. 8, it is found that creep progresses substantially in the non-loaded area. This suggests that in the non-loaded area, the interference is lost or some clearance is generated as shown in Fig. 18, where some geometrical displacement appears between the inner ring and the shaft. FEM analysis also shows almost zero contact pressure at the center of the fitting surfaces in the non-loaded area, with some clearance at a part of the axial position. For the loaded area, on the other hand, no sliding was observed under the 20 kN radial load, but slight sliding was found under the 30 kN radial load. This is considered to be based on the same mechanism as that of the interference fit, which is discussed in the following subsection.

5.2 In Case of Interference Fit

From the FEM analysis result shown in Fig. 17, peaks of sliding were observed at positions slightly displaced from the position of the rolling elements towards the 0° side. Also, the experimental result shown in Fig. 9 revealed that the inner ring's relative movement stopped when the rolling element was passing. As a result, the inner ring is considered to slide based on the following mechanism.

As shown in the conceptual diagram of Fig. 19, for the rolling elements in the 90° to 180° area, the inner ring slides minutely relative to the shaft when the shearing stress $\tau(\theta)$ generated due to the rolling element load surpasses the friction force by the contact pressure $\mu \sigma(\theta)$ ($\tau(\theta) > \mu \sigma(\theta)$). And at the position where the contact pressure caused by the passing of rolling element reaches its maximum, the sliding inner ring sticks to the shaft. Repetition of such minute sliding of the inner ring relative to the shaft is considered to build up, resulting in causing creep.

Furthermore, from the experiment result shown in Fig. 9, the inner ring slides in the opposite direction at the 200°~280° area. This is considered that sliding occurs only in this area without any sticking of the inner ring because of the peak of sliding at the position back of the rolling element (since FEM output is bilaterally symmetrical).

6. Conclusions

1) Circumferential positions at which creep was generated were confirmed experimentally for both transition fit and interference fit.
2) Generation mechanism of the inner ring creep was studied, though only qualitatively, by combining experimental and FEM analysis results.

References


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