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A STUDY ON BEARING CREEP MECHANISM WITH FEM SIMULATION

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ABSTRACT

Because of the continuous quests for high performance and compact structure of automobile and machine in recent years, rolling bearings are required to work under harder conditions of high speed and heavy load than before. The applications of hard condition may lead to a greater likelihood of happening of bearing malfunctions such as flaking, wear, creep, fracture etc. In this paper, the phenomenon called outer ring creep occurring in bearings subject to non-rotating load is discussed.

Outer ring creep is referred to that bearing outer ring rotates relatively to the housing in certain applications. Outer ring creep may result in such problems as unusual noise and vibration and may cause wear of housing and outer ring. If abrasive particles caused by wear of the ring and housing enter the raceway, the bearing may be damaged and destroyed.

Conventionally, the problem of outer ring creep was considered to be a result of rotating bearing load. However, even if the direction of radial load remained relatively unchanged, outer ring creep is observed in many cases. The generation mechanism of this kind of outer ring creep has not yet been made clear till now.

With FEM simulation and test verification, we analyzed the phenomenon of outer ring creep under non-rotating load. We concluded that outer ring creep under non-rotating load is a result of localized strain and rippling deformation caused by rolling elements.

In this paper, only outer ring creep is discussed below, but the similar result can be obtained for inner ring creep.

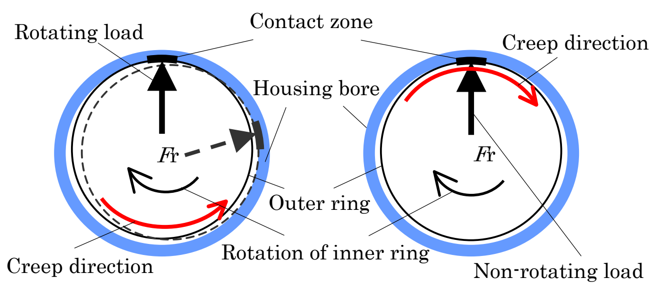
INTRODUCTION

Early prior research jobs on bearing outer ring creep have been reported since 1960's [1, 2, 3 and 4]. Outer ring creep discussed in these reports generally occurred under condition that bearing radial load rotated relatively to the housing. The relative direction of outer ring creep was opposite to the direction of inner ring rotation. Conventionally, the relative-rotating radial bearing load was considered to be the main cause for this kind of outer ring creep.

However, a quite different situation of outer ring creep can be found in many cases of bearing applications. The phenomenon of slight rotation of outer ring happens even though the radial bearing load does not rotate. In these cases, the direction of outer ring creep is usually found to be in the same direction of inner ring rotation.

In Fig. 1, the difference between the situation of outer ring creep under rotating load and that of outer ring creep under non-rotating load is shown.

It is supposed that the rolling bearings are mounted in the fixed housing parts and the bearing inner rings rotate clockwise. As shown in Fig. 1 (a), the bearing outer ring is pressed against the housing bore by the radial load Fr in its direction, and a tight contact zone is produced in a moment. If the diameter of outer ring is smaller than the diameter of housing bore due to a fitting tolerance, the contact zone between outer ring and housing may 'move' along the circumference of the housing bore. As a result, the outer ring rolls along the bore circumference and appears to rotate in the opposite direction of inner ring rotation. The mechanism of this kind of outer ring creep has been concluded by many reports [1, 2, 3 and 4].



(a) With rotating load (b) With non-rotating load

Fig. 1 Comparison of two kinds of outer ring creep

On the other hand, outer ring creep has been observed even though the direction of radial load keeps fixed, as shown in Fig. 1(b). In this case, outer ring appears to rotate slightly in the same direction of inner ring rotation, while the position of the tight contact zone between outer ring and housing remains stationary. Therefore, the former explanation for the mechanism of outer ring creep is no more applicable in this case.

MECHANISM INVESTIGATION WITH SIMULATION

To investigate the mechanism of outer ring creep occurred under the condition of non-rotating load, FEM simulation was carried out with the model shown in Fig. 2.

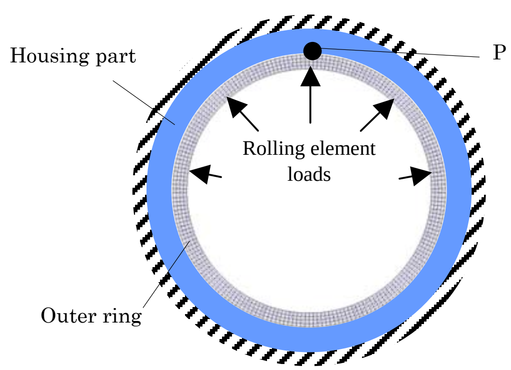
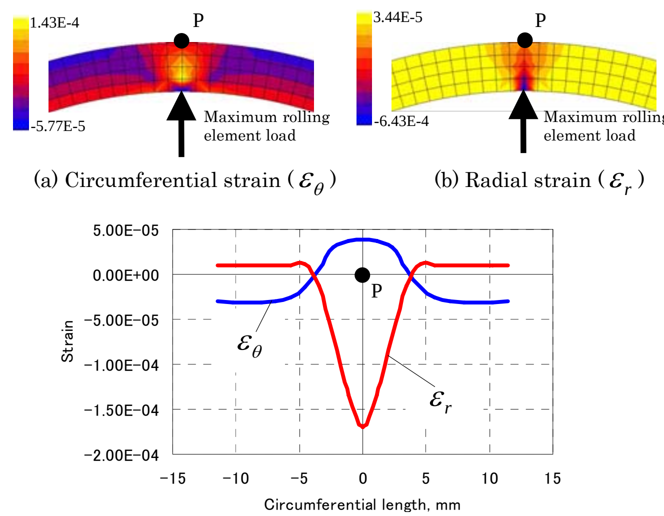


Fig. 2 FEM model for simulation

To reduce the computation time, a simple 2D FEM model was used at first. The outer ring of bearing was modeled in elastic mesh, and the housing model was made in rigid body. The contact condition was applied between outer ring and housing with a friction coefficient set at 0.2. The rolling element load distribution calculated by additional software was directly applied to the outer ring without rolling element model. Associated with rolling movement, the changes in rolling element loads were considered by controlling the distribution of node loads on the model. The rigid body of housing was fixed to the ground.

As an example, we give the results of our simulation for a deep groove ball bearing (6207). The condition of bearing loading ratio (*Fr*/*Cr*) was set at 0.2.

Fig. 3 shows the results of elastic strain distribution of the outer ring. Fig. 3 (a) shows the distribution of circumferential strain in the area near the position of maximum rolling element load, while Fig. 3 (b) shows the distribution of radial strain in the same area. The graph in Fig.3 (c) shows the distribution of strain on the outside diameter of the outer ring.



(c) Strain distribution on outside diameter of outer ring

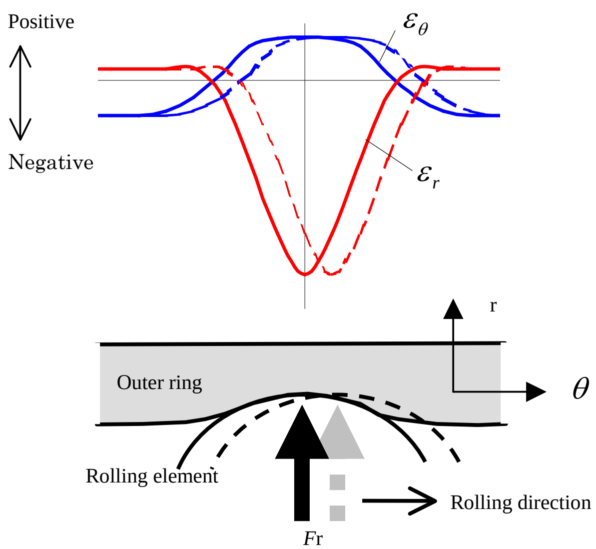
Fig. 3 Distribution of elastic strain of outer ring

Within the local area on the outside diameter near reference point P, the circumferential strain ε_θ took a positive value and the radial strain ε_r took a negative value. It indicates that the outer ring stretched in the circumferential direction and shrunk in the radial direction under the contact pressure between the outer ring and housing.

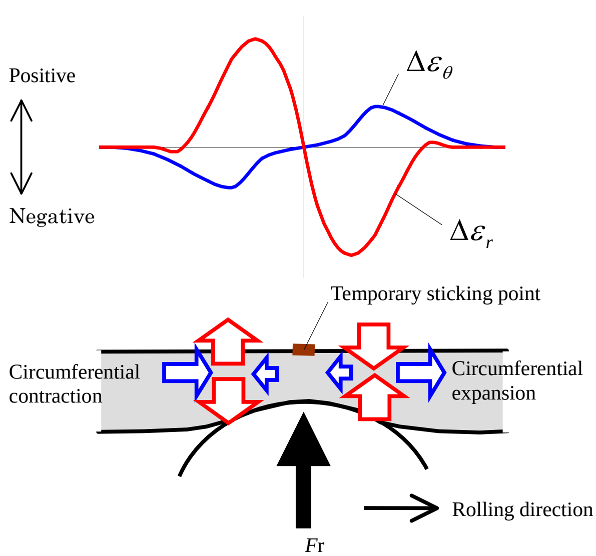
Obviously, when rolling element load rotates in the direction of inner ring rotation, the distribution of local strain moves accordingly in the same direction. Fig. 4 shows an image of the changes in strain of outer ring caused by the passing of rolling element.

Considering a very short moment for which a rolling element rolls forward, two distribution of elastic strain in the area around point P can be obtained. In Fig. 4 (a), the distribution in solid line is relative to the initial position of rolling element, and the dotted line is relative to the final position of the rolling element. At each moment, the distribution of strain is symmetrical with respect to the position of rolling element.

Fig. 4 (b) shows the distribution of strain variations ($\Delta\varepsilon_\theta, \Delta\varepsilon_r$) associated with the movement of rolling element. According to the direction of the movement of rolling element, the strain variations are distributed differently in front of and behind the rolling element. The distribution of $\Delta\varepsilon_\theta$ takes a positive value in front of the rolling element and takes a negative value behind it. At the same time, $\Delta\varepsilon_r$ takes a negative value in front of the rolling element and takes a positive value bind it.



(a) Strain distribution caused by rolling element load



(b) Strain variation caused by rolling element movement

Fig. 4 Local deformation variation resulting from passing of rolling element load

In the circumferential direction, local expansion in front of the rolling element and local contraction behind the rolling element will occur repeatedly with each passage of rolling elements. In addition, high pressure at the point just under the rolling element load may cause temporary sticking.

Fig. 5 shows the result of circumferential displacement of the local area near point P on the outside diameter of outer ring according to the movement of rolling element load. The circumferential displacement of point P is about 0.0005 mm and 0.001 mm when rolling element load rotated clockwise for 0.5 and 1.0 pitch (the distance between neighboring rolling elements). In the calculation, the changes in the size of rolling element load corresponding to the position of rolling element were taken into considered.

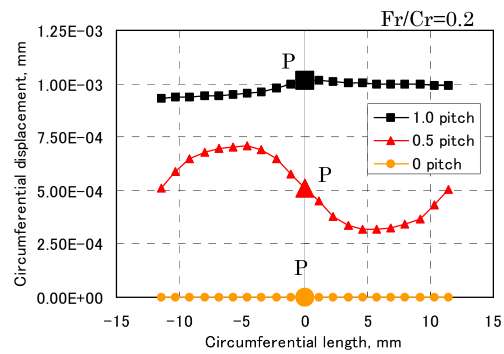


Fig. 5 Circumferential displacement caused by the movement of rolling element load

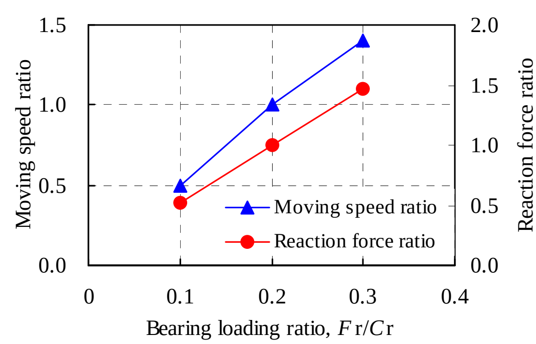


Fig. 6 Influence of bearing load on outer ring creep

By changing the size of bearing load (Fr), the influence of bearing load on the moving speed of point P has been observed. The speed was calculated from the displacement of point p and the moving time of rolling element load. In addition, by restraining point P in circumferential direction, the reaction force has been calculated to evaluate the driving force caused by the movement of rolling element load. Fig. 6 gives the results of moving speed and reaction force shown as ratios in relation to the reference result calculated with the condition of

Fr/*Cr*=0.2. It is recognized that both of moving speed and reaction force increased with the increase in bearing load.

From these results, it can be considered that each passage of rolling element generates some driving force to rotate the outer ring in the same direction of inner ring rotation.

TEST FOR EXAMINATION

To exam the conclusion obtained from FEM simulation in the previous section, the test device shown in Fig. 7 was used to reproduce outer ring creep. In this test, outer ring creep was recorded by a video camera so that creep speed is easy to be calculated.

In the test, a load cell connected to the outer ring with a connecting rod was used to measure creep torque. At the same time, dynamic torque of the bearing was measured on the driving shaft.

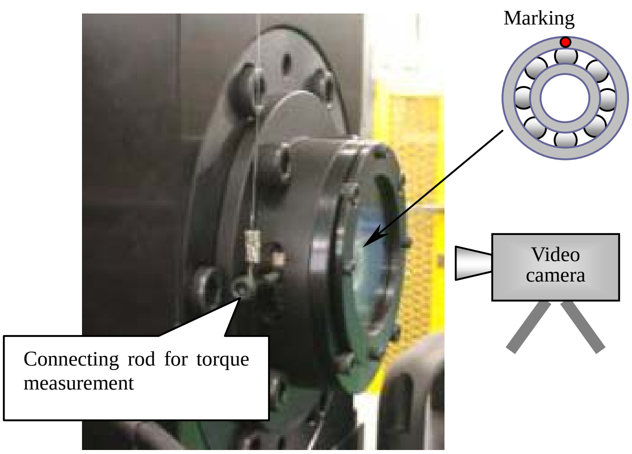


Fig. 7 Test device for outer ring creep observation

Table 1 Bearing conditions for outer ring creep test

Items	Conditions
Bearing type	Deep groove ball bearing (6207)
Rotational speed of inner ring	1000 to 5000 rpm
Loading ratio (*Fr*/*Cr*)	0.1 to 0.4
Lubricant method	Grease
Fr: radial load *Cr*: basic dynamic radial load rating	

The details of test conditions are shown in Table 1, and the results of test are shown in Fig. 8, Fig. 9 and Fig. 10.

As shown in Fig. 8, outer ring creep speed changes corresponding to rotational speed of inner ring, and increases with the increase in bearing load. Because of the fact that outer ring creep torque is about 50 times larger than dynamic torque, dynamic torque is not recognized to be the cause for outer ring creep. In addition, creep torque and dynamic torque increase with the increase in bearing load, but both of them have few changes in value with the increase in rotational speed of inner ring.

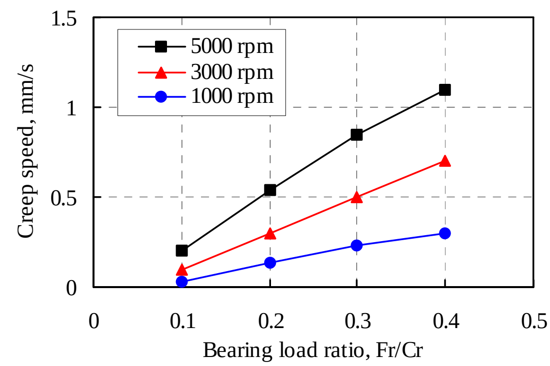


Fig. 8 Test results of outer ring creep speed with different bearing loads

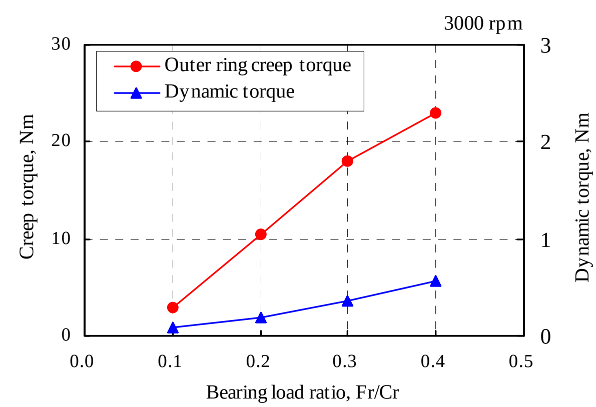


Fig. 9 Test results of torque with different bearing loads

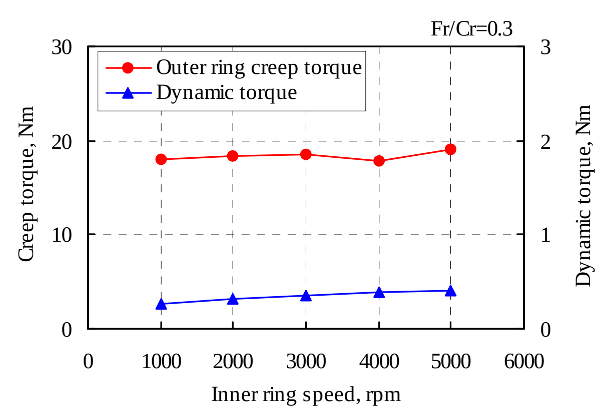


Fig. 10 Test results of torque with different inner ring speed

The experimental results of creep speed and creep torque are recognized to be essentially correspondent with the results of FEM simulation. From all of the results and findings, it can be concluded that outer ring creep under non-rotating bearing load is a result of local deformation of outer ring resulting from the passing of each rolling element.

INFLUENCE OF HOUSING STIFFNESS ON OUTER RING CREEP

Besides bearing load and rotational speed of inner ring, there are many factors, such as outer ring stiffness, number of rolling element, clearance between housing and outer ring etc., affecting the likelihood of outer ring creep. The authors have discussed these factors in an earlier report [5].

Not only the structure of bearing itself, the structure of housing is considered to have a great influence on the likelihood of outer ring creep as well. With FEM simulation, we analyzed the relationship between creep displacement and housing stiffness. Fig. 11 shows an example of model with both outer ring and housing created in elastic mesh.

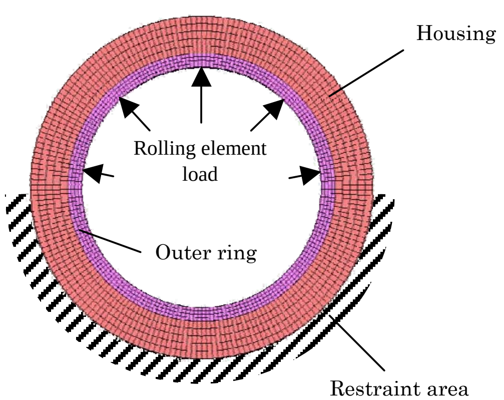


Fig. 11 FEM model with elastic meshes for both outer ring and housing

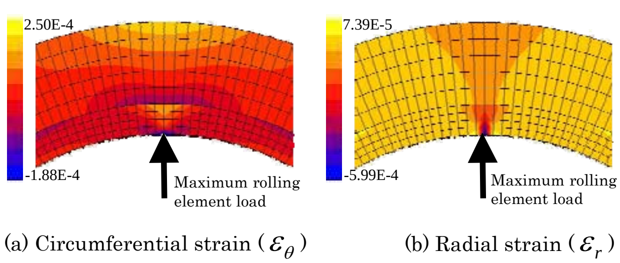


Fig. 12 Distribution of strain of outer ring and housing

Fig. 12 shows the results of elastic strain obtained by FEM simulation. The thickness of housing was 10 mm and the opposite side to load zone was fixed. Other conditions of bearing were same as the model described in the previous sections. On the contact surface between the outer ring and housing near the maximum rolling element load, outer ring stretches more than housing in the circumferential direction. At the same time, outer ring shrinks more than housing in the radial direction.

Fig. 13 shows the changes in circumferential displacement for different thickness (t) of housing. The displacement results are calculated with moving rolling element load for a distance of one pitch. The tendency is clear that outer ring creep may occur easily in a thinner housing which has less stiffness.

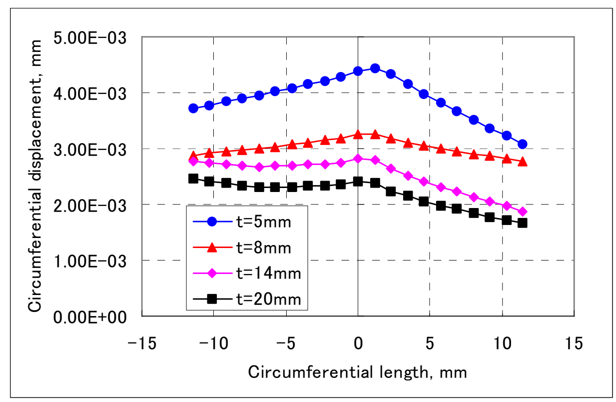


Fig. 13 Outer ring creep likelihood with different housing stiffness

In spite of the difference in absolute values, the results of displacement distribution from elastic housing model agree basically with the results from rigid housing model. Generally, housing is considered to have less local deformation than outer ring, so that a rigid model for housing is reasonable for qualitative analysis with less computation time.

CONCLUSION

Different from outer ring creep in the opposite direction of inner ring rotation, outer ring creep in the same direction of inner ring may occur under non-rotating bearing. By FEM simulation and test, we concluded that outer ring creep under non-rotating load is a result of localized strain and rippling deformation caused by rolling elements.

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