

A Creep Mechanism of Rolling Bearings

Tsuyoshi NIWA*



The mechanism of creep phenomena, in which a bearing ring gradually moves circumferentially to the stationary shaft or housing mating with the ring, has not been clarified yet. The author found a “surface traveling-wave creep” mechanism based on a numerical analysis and theoretical consideration. The creep is featured by movement in the same direction as the bearing rotation. In addition to the creep mechanism, this paper proposes a design requirement to prevent the creep.

1. Introduction

1.1 Creep in the opposite direction of rotation

Soda ¹⁾ describes two mechanisms regarding the creep phenomenon of the bearing ring in the opposite direction of rotation.

One of them is relatively well known and is caused by clearance between the ring and the housing or shaft, as shown in Fig. 1. Namely, when the rotational load acts on the bearings, the ring rotates on the fitting surface of the housing based on the change of the load direction. If the clearance between the fitting surface and ring is c , the ring delays by πc per rotation of the bearing, causing creep in the opposite direction from the rotation of the bearing.

The other one is caused by elastic deformation and slippage of the ring when there is no clearance. While Imai ²⁾ also proved presence of this mechanism

experimentally, Soda, by pointing out an example of a canister with a rubber band around it, as shown in Fig. 2, explained that creep occurs “because a small slippage between the rubber band and the tea canister at a certain point below the load accumulates moving forward as the canister rolls on.” At the beginning, the rubber band deforms by the load of the tea canister and stretches out in the circumferential direction. This deformation is symmetrical and the slippage is also identical between the right and left sides, therefore creep, which is a movement to one direction, should not occur. However, when the tea canister rolls, the deformation caused by the previous slippage still remains, causing asymmetry. Creep is then produced as the slippage to one direction increases. The rubber band creeps to the opposite direction from the rolling direction of the canister.

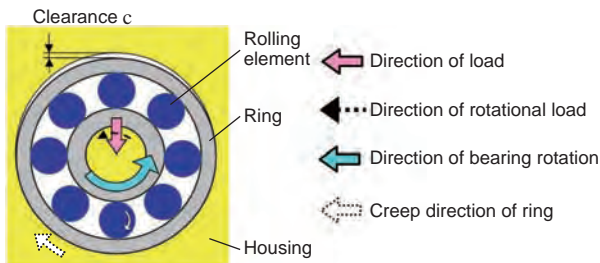


Fig. 1 Creep by clearance

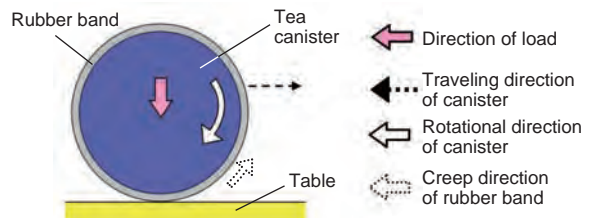


Fig. 2 Creep by rubber band slip

*CAE Dept., Automotive Business HQ

1.2 Creep in the same direction as rotation

On the other hand, actual bearings often creep in the same direction as rotation. This phenomenon can be explained by indicating the mechanism for the ring to creep in the same direction as the traveling direction of the rolling elements.

Ten et. al³⁾ explains that “We consider that force to rotate the outer ring on the circumference was produced from the strain that occurred every time the rolling elements traversed, which pushed the outer ring forward, little by little, generating creep.” Fig. 3 shows the schematic diagram.

This mechanism, explaining that creep comes from the accumulated strain moving forward on the circumference, matches with the explanation of Soda and can be considered to reflect the actual phenomenon. However, while Sakajiri et al.⁴⁾ pointed out some interesting remarks on the wavy deformation of the outer ring surface, the explanation of Ten et al. does not give mention to this finding and therefore, does not give a clear picture of the phenomenon.

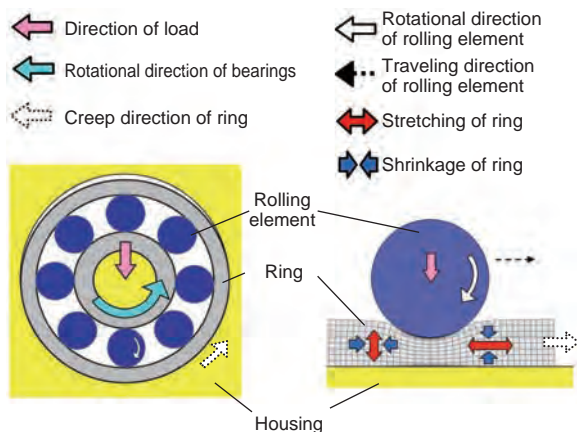


Fig. 3 Creep by strain

1.3 Proposal from our study

In this study, we provided a hypothesis that the traveling wave is produced on the ring surface and this traveling wave moves the ring and produces creep. Using an FE analysis, creep can be produced relatively easily. However, there is currently no literature pointing out that creep is a transfer phenomenon by traveling waves. This may be caused by the fact that this phenomenon is unique and the explanation of the behavior itself is difficult. Therefore, we will start explaining this mechanism using familiar devices. Then, we will also discuss conditions to restrict creep from the principles of generating traveling waves.

2. Mechanism of traveling wave type creep

2.1 Transfer of ultrasonic motor

We look at the operation of an ultrasonic motor. In a disk-type ultrasonic motor, traveling waves are excited by piezoelectric elements on the surface of an elastic body. This produces an elliptic motion on the rotor in the opposite direction of the traveling waves on the surface of the elastic body⁵⁾.

Fig. 4 shows the transfer mechanism of the ultrasonic motor. The rotor, pressed on the elastic body, moves in the opposite direction from the traveling waves by the elliptic motion of the surface.

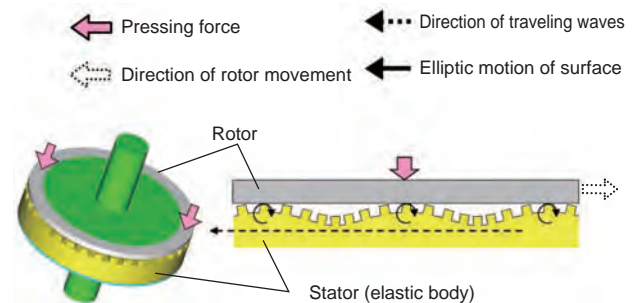


Fig. 4 Mechanism of ultrasonic motor

2.2 Self-transfer of ring due to the traveling waves

According to Sakajiri et al.⁴⁾ the traveling waves in bearings are produced when the load from the rolling elements acts on the ring surface and the fitting surface immediately below that point is pushed out. This causes the surface to become wavy up to several microns depending on the load. When the bearings rotate, the rolling elements also move, with which these surface waves become traveling waves.

In the ultrasonic motor application, the traveling waves produced at the stator move the rotor. With the bearing ring creep, as shown in Fig. 5, traveling waves are produced to the ring itself which cause the it to creep. In terms of the direction of creep, the ring acts on the housing in the opposite direction of the

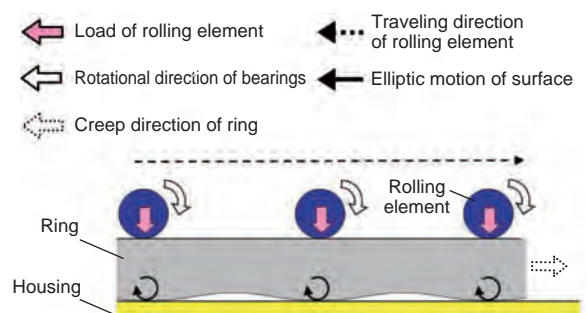


Fig. 5 Traveling-wave creep of bearing ring

traveling direction of the rolling elements. However since the housing is fixed, the ring is pushed back resulting in traveling in the same direction as the rolling elements, that is, rotating in the same direction as the rotation of the bearing.

The traveling waves produced on the ring surface behave like peristaltic motion in the circumferential and radial directions throughout the loaded area. The rotational movement opposite to the traveling waves at the fitting surface immediately below the rolling elements is characteristic of this.

In this study, this transfer phenomenon of the ring by this mechanism is called "traveling wave type creep."

3. Conditions to restrict the traveling wave type creep

Ten et al. ³⁾ pointed out that increasing the number of rolling elements for load distribution and using thicker ring are effective for reducing the local strain. However, conditions to fundamentally restrict creep are not indicated. In the following sections, we will discuss the design requirements necessary for restricting the traveling waves.

3.1 Behavior of a point within a body

As shown in Fig. 6, it is considered that a point located at a relatively shallow area of a body moves in a loop when load from traveling rolling elements is applied on the surface of the body. When a rolling element passes immediately above (1), the point is pressed down and when the point is between two rolling elements (3), it moves up closer to the surface. In between those positions (2) and (4), it moves to the opposite sides of the rolling elements. This micro behavior is repeated.

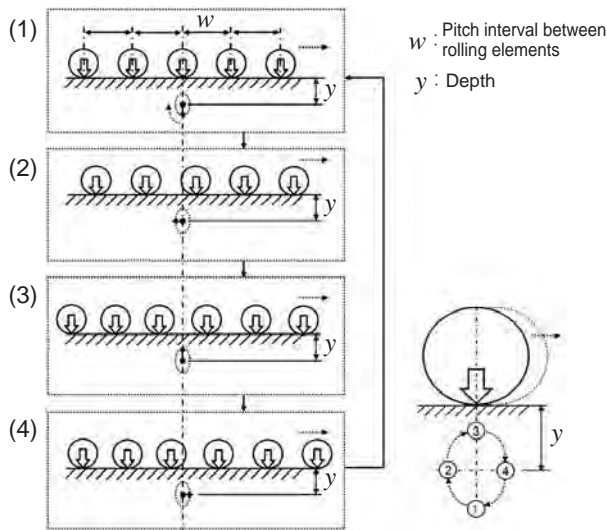


Fig. 6 Behavior of internal point under loading

3.2 Evaluation by Bussinesq equation

We examined the behavior of the point in the body using the Bussinesq's displacement equation ⁶⁾ which assumes plane strain.

Fig. 7 shows the analysis model. Following the model of Imai ²⁾, we simplified the model assuming that the load of the rolling elements q_i is distributed following the sinusoidal function. The displacement produced to the point at the depth y in the middle of the loaded area affected by the i th load is described by Equations (1) and (2). Fig. 8 shows the Lissajous figure indicating the locus of the point in the body which is displaced by the load of 5 traveling rolling elements.

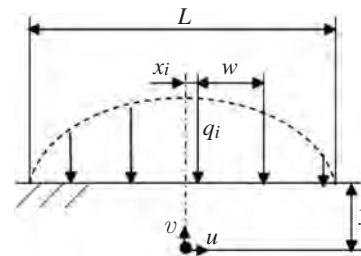


Fig. 7 Analytical model

$$u_i = \frac{q_i}{2\pi G} \left\{ \frac{x_i y}{x_i^2 + y^2} - (1 - 2\nu) \tan^{-1} \left(\frac{x_i}{y} \right) \right\} \dots\dots\dots (1)$$

$$v_i = \frac{q_i}{2\pi G} \left\{ \frac{x_i^2}{x_i^2 + y^2} + 2(1 - \nu) \log \left(\frac{\sqrt{x_i^2 + y^2}}{B} \right) \right\} \dots\dots\dots (2)$$

- L : Length of load zone
- q_i : Load of rolling element i
- x_i : Position of rolling element i
- u, v : Displacement
- G : Shear modulus
- ν : Poisson's ratio
- B : Integral Constant
- w : Pitch between rolling elements

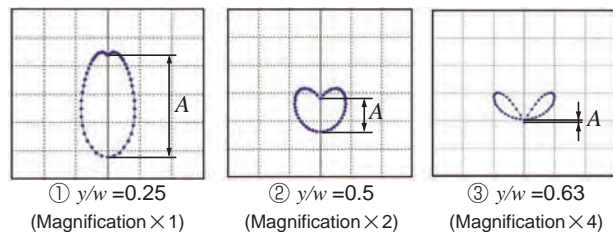


Fig. 8 Locus of internal point

From Equations (1) and (2), if the ratio of the pitch w and the depth y is constant, that is, if the conditions are homologous, the shape and size of the loop in the Lissajous figure become the same. For convenience, B of Equation (1) was set to 1, however, it does not affect the shape and size of the loop.

In this study, we considered that the movement of the elliptic motion in Fig. 6 and 8 is the source of the creep movement by traveling waves and evaluated the amplitude A of Fig. 8, as the index of the elliptic motion.

3.3 Condition to restrict the traveling wave

Fig. 9 shows the examined result of the behavior of amplitude A in Fig. 8. While the amplitude A is proportional to the sum of the rolling element load $\sum q_i$, it converges under the conditions of the ratio of depth y / pitch interval $w > 0.6$.

The ring, housing and shaft are in contact, therefore, the above discussion that assumes continuous body does not generally apply. However, if we consider the depth y as the thickness of the ring t , under the condition of Equation 3 below,

$$\text{Thickness of ring } t / \text{pitch interval of rolling elements } w > 0.6 \quad \dots\dots\dots (3)$$

the traveling waves, which is the main driving force of the transfer phenomenon, converge. Therefore, creep should be restricted and is depicted in Fig. 10.

From the above, we consider that the conditions for producing traveling wave type creep are in the ratio of the thickness of the ring and pitch interval rather than the load and size of the bearing components.

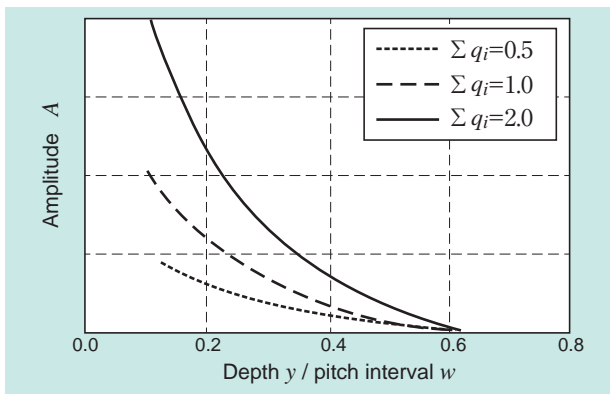


Fig. 6 Amplitude of locus

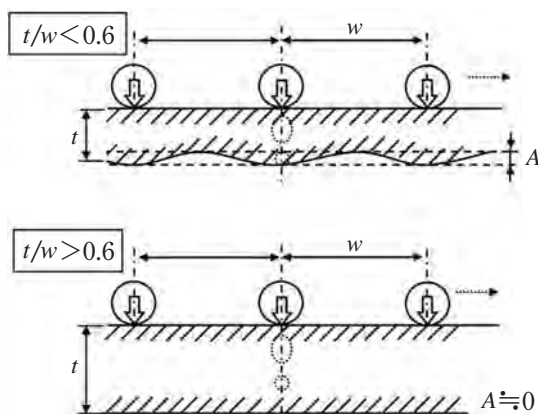


Fig. 10 Thickness of bearing ring and traveling-wave

4. Summary

- (1) We have clarified the phenomenon where the ring creeps in the same direction as the bearing rotation and presented a mechanism called "traveling wave type creep".
- (2) We have presented the mechanism to restrict the traveling wave type creep under the condition of the thickness of ring / pitch interval of rolling elements > 0.6 .

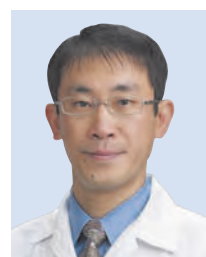
In addition, as further complex contact behavior on the fitting surface due to traveling waves is being clarified⁷⁾, we are planning to study it in details.

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Photo of authors



Tsuyoshi NIWA
CAE Dept.
Automotive Business HQ