Investigation of the Bearing Damage Progression Starting from Cone Creep of a Railroad Axle Journal Bearing

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Journal bearing cone "creep" phenomena, leading to cones which "spin" on a railroad axle journal, can potentially be a cause for wear and a source of heat generation. It is, however, still unknown how rapidly an axle and bearing deteriorate after the initiation of the cone creep. A cone creep simulation test using a full-scale railroad bearing was conducted in a laboratory to investigate the bearing damage progression starting from cone creep. Test results gave changes in bearing temperature, vibration, and dimensional clearances between the axle journal diameter and the cone bore, due to cone creep.

Keywords: *axle journal bearing, cone creep, failure process*

1. Introduction

In railway vehicles, rolling element bearings are used for axle journals, shafts of main motors, running gears, and others. Bearing damage can be a result of both internal and/or external causes. Damaged bearings are investigated to reveal the cause and to try to prevent a recurrence of a similar failure. It is, however, difficult and often impossible to analyze the bearing damage progression associated with high heat generation and bearing seizure, because of the typical destruction of the parts with this type of failure.

A cone creep phenomena of a railroad axle journal bearing, although very rare when proper interference fits are used, can lead to wear and cones spinning on the journal, which can lead to a bearing burn-off and potential fracture of the axle. To prevent this type of incident is a significant challenge from the point of view of safety and economics in the railway industry.

In the U.S., a number of field simulation tests have been conducted using bearings with various types of defects, which have been removed from actual revenue service, in order to clarify the mechanism and develop a bearing burn-off detection system [1-6]. This activity has illustrated a failure process in the final stage of bearing burn-off. It is, however, still unpredictable as to how rapidly an axle and bearing deteriorate after the initiation of the cone creep. Moreover, a simulation test has not been performed for an axle bearing of a high-speed train. High-speed trains, such as the Shinkansen trains in Japan, are typically designed for passenger service, where safety and reliability are critical.

This work is intended to obtain information which can be instrumental in understanding and clarifying the bearing system failure process starting from cone creep, through a cone creep simulation test using a full-scale railroad bearing in a laboratory.

2. Test descriptions

2.1 Test specimen

The test bearing used was a cartridge tapered roller bearing, which was developed as a journal axle bearing for Japanese high-speed trains. The section view of the test bearing is shown in Fig. 1. The test bearing itself was a new bearing lubricated with new grease (Nerita 2858: Showa Shell Sekiyu K.K.), the amount of which is approximately 320g.

The test axle provided a nominal "line-to-line", or zero interference fit of 0.000mm for the "outboard" cone seat to produce a cone creep state or condition, while maintaining a normal interference fit for the "inboard" (cone nearest to the drive motor) cone seat. The standard interference fit for this application ranges from 0.068mm to 0.102mm.

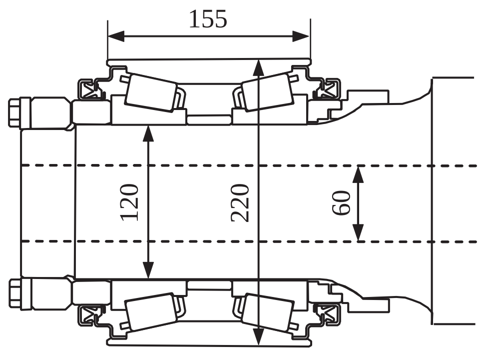


Fig. 1 The section view of the test bearing. (Metric)

2.2 Test equipment and data collection

Figure 2 illustrates the schematic view of the assembly of the test bearing and axle. A radial load is applied from the top of the test bearing.

Five resistance temperature detector (RTD) tempera-

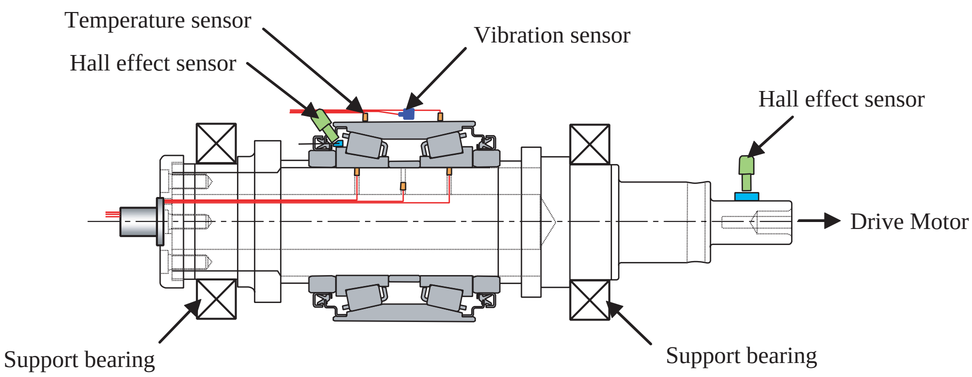


Fig. 2 The concept of the assembly of test bearing and axle.

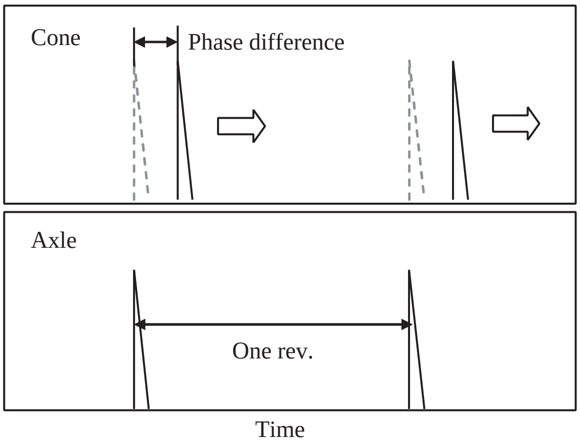


Fig. 3 An example of cone and axle pulses.

ture sensors were installed to measure temperatures of the test bearing and axle, as shown in Fig. 2. The two sensors for the cup OD temperatures were placed at the exterior surface cup using the holes made on the sleeve jacket. The sensors for the cone bore temperatures were placed using radial holes in the axle. A sensor for axle temperature measurement was placed between the two cones. Ambient temperature was also monitored.

In order to monitor the cone motion around the axle, two hall effect sensors were installed and the targets (small iron pieces) for the sensors were mounted on the cone large rib OD and axle, which allow independent detection of one pulse per revolution for both the cone and axle. Figure 3 displays an example of the pulses detected during the test. When the cone creeps around the axle, a phase difference between the two pulses can be developed, which can be converted to a cone rotation angle relative to the axle. A vibration sensor (tri-axis) was attached on the sleeve jacket. All the above mentioned variables were recorded on digital audiotapes during the test.

2.3 Test condition

A test condition was determined based on the actual operating condition for Series 500 Shinkansen train that travels at speeds of up to 300 km/h. The average dynamic equivalent load of approximately 110 kN, at the maximum speed was applied to the test bearing. When the train speed V = 300 km/h and the wheel diameter D_w = 860 mm, the revolution number of the axle N = 1852 rpm.

3. Results and discussion

3.1 Cone creep performance

Figure 4 contains the variations of the cone motion rate, bearing temperatures, vibration, axle OD and cone bore, plotted as a function of the operating sequence time. The outboard cone began to creep immediately when the axle speed increased after the test started. The test was terminated after approximately 324 hours (the equivalent of approximately 97,200 km) of operation. The test machine was paused several times during the test due to review the test bearing and axle at approximately 72 and 220 hours and to review the condition of the test setup and data acquisition, etc. At the conclusion of testing, the test bearing began to emit white smoke and generated noise. Although the bearing did not burn-off, it was considered to have reached the point of incipient thermal failure. Within the test duration, the cone creep failure process can be categorized into three stages depending on the cone motion as follows:

Stage I:

The cone crept at extremely slow rates of less than 0.25 rpm around the axle, and the cone motion was not consistent. Additionally, there was a period of time when the cone stopped creeping. It appears that the cone motion was affected by the variation of friction at the axle/cone interface, resulting from the wear products from fretting and metal transfer. However, there was no sign of bearing deterioration from appearance and the axle OD and the cone bore did not show any distinct change. In addition, no significant change in the bearing temperature and vibration was observed. It can be stated from this evidence that bearing deterioration does not occur in the early stage of cone creep, although the fretting wear on the axle OD is present.

Stage II:

The cone motion rate increased gradually up to approximately 8 rpm. It is clear that this cone motion rate increases as the gap between the axle OD and cone bore increases, primarily due to fretting wear on the axle. The bearing temperature showed a slight increase in this stage, but still relatively low in magnitude. The bearing vibration was still in the same level as Stage I, which suggests there was no significant damage in the bear-

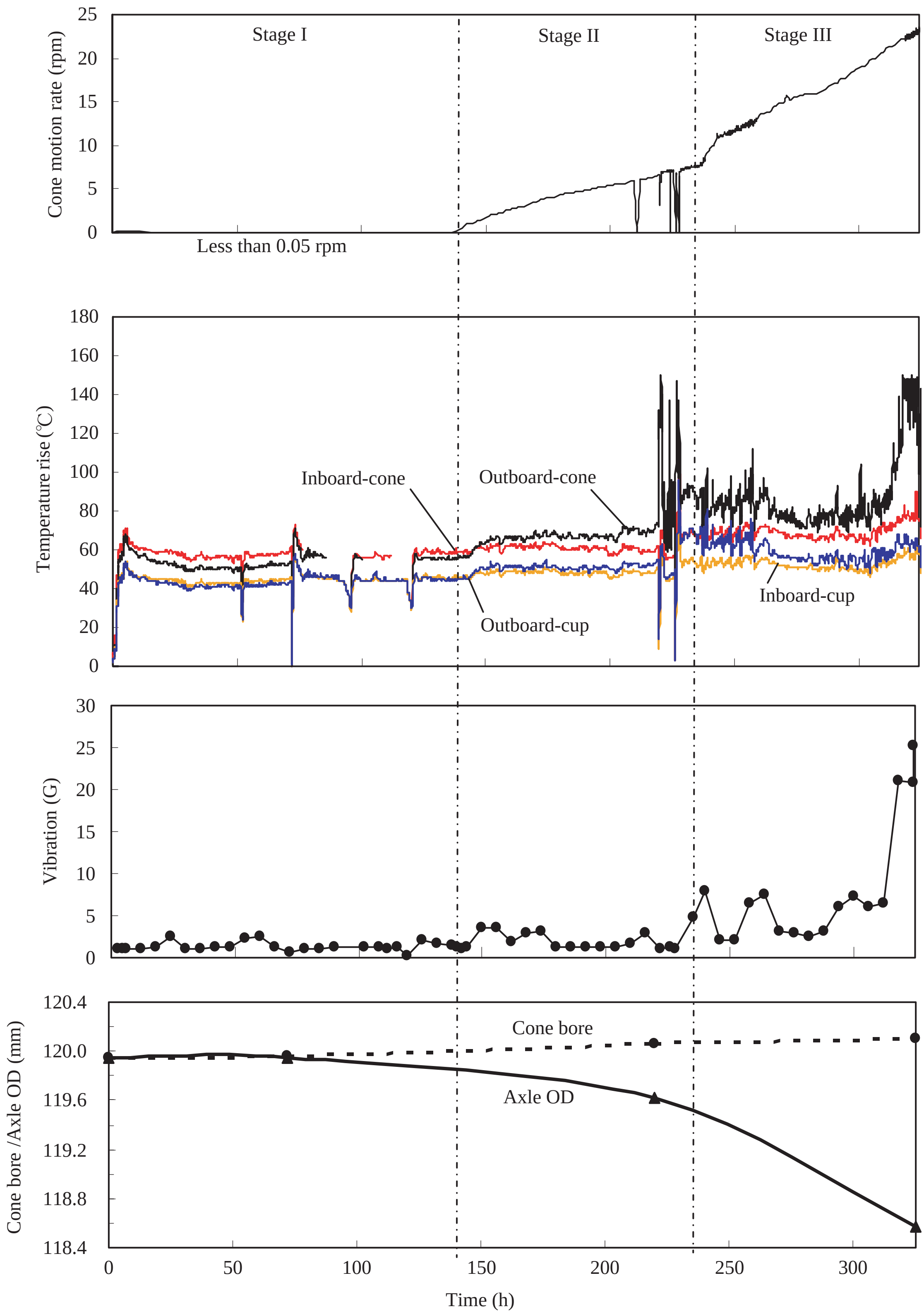


Fig. 4 The variation of cone motion, temperature, vibration, cone bore and axle OD.

ing. Therefore, it can be stated in this stage that the gap begins to increase due primarily to axle wear, and yet there is still no significant damage to the bearing.

Stage III:

In this stage, the cone motion rate climbed rapidly compared with Stage II, and reached approximately 23 rpm at the end of the test. The axle was visibly and measurably grooved. The wear rate of the axle in this stage was clearly higher than Stage II. The bearing temperature showed a remarkable variation and reached approximately 150℃ above ambient (possible higher temperature on raceway surface). In this stage the cone is considered to have reached the level of “spinning”, or “gross relative motion”, on the journal. At this point the temperature increase begins to affect the grease, causing rapid oxidation and deterioration, a loss of operating viscosity, and eventually leading to marginal lubrication of the bearing contact surfaces. At the end of this stage, the vibration and noise increased sharply due to the cup and roller spalling. From this evidence, it can be stated that this stage is where the gap increase affects the bearing internal operation.

3.2 Visual inspection

(a) Axle

Figure 5 displays the axle bearing seats after 72, 220 and 324 hours of operation respectively, which provide visible marks of cone creep on the outboard cone seat. Although the 72 hours operation does not bring a visible grooved axle, there is evidence of fretting wear, abrasion and metal transfer caused by the relative cone motion. The axle cone seat after 220 hours operation is slightly grooved and exhibits uniformly mild wear. At the end of the test, the axle cone seat is visibly grooved and exhibits the distinct reduction of the axle OD.

(b) Bearing

Grease:

Figure 6 displays both the outboard and inboard cone assemblies. The grease on both assemblies had become discolored and contaminated. Grease on the outboard cone assembly was heavily oxidized (“carbonized”), while the grease on the inboard cone assembly was not significantly oxidized. Table 1 shows the penetration and content of Fe after the test.

Table 1 The penetration and content of Fe in the grease

	Penetration (25℃, 0W)	Fe (mass%)
Cup	131	6.82
Inboard cone	183	3.36
Outboard cone	127	6.65
Inboard seal	252	1.42
Outboard seal	154	6.04
New grease	261	0.00

Cones:

Oil staining was observed both on the race adjacent to the large rib of the outboard cone and on the race adjacent to the small rib side of the inboard cone. There was no visible external damage on both cone bore surfaces. There was some slight scoring on the large rib face of the outboard cone, while that of the inboard cone was still in good condition.

Rollers:

Oil staining was found both on the roller body surfaces at the large end side of the outboard cone rollers and at the small end of the inboard cone rollers. Significant scoring on the large end of the outboard rollers was observed. As shown in Fig. 7, one of the inboard rollers developed a spall on the roller body adjacent the small end.

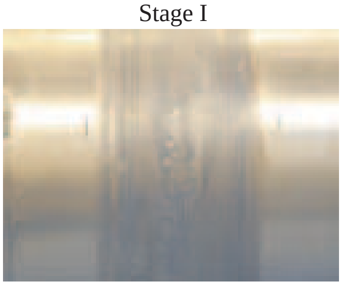
Cages:

No cage damage was noted.

Cup:

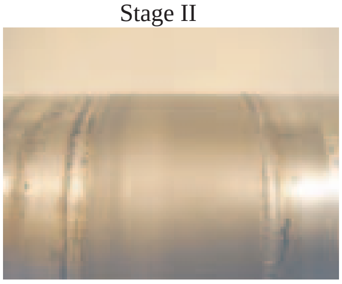
Spalling can be observed on the outboard cup race

Stage I



(a) 72h

Stage II



(b) 220h

Stage III

(c) 324h

Fig. 5 The appearance of the axle outboard cone seat.

(a) Outboard cone assembly

(b) Inboard cone assembly

Fig. 6 The cone assemblies after the test.

Fig. 7 The spalled roller.

Fig. 8 The inboard cup race with spalling.

as shown in Fig. 8. Bruising caused by metal debris from the spalling can be recognized on the race.

Seals:
No seal damage was noted.

3.3 Failure process from cone creep

Figure 9 displays a possible failure sequence starting from cone creep. Increasing severity of cone creep, or relative rotation of the cone on the axle, results in

Condition:	Cause:	Effect:
Cone Creep	Inadequate interference fit between cone bore and axle journal OD	Allows or facilitates fretting and wear surface under the cone with inadequate fit
Cone "Spinning"	Gross loss of fit or retention of the cone on the axle, allowing the cone to turn faster relative to the axle speed	Accelerates the friction and wear, and generates increasing amount of heat, wear debris, accelerates the grease oxidation rate, and results in thin film lubrication conditions
Increased Heat Generation	Friction and cone spinning rate increases	System goes into an upward thermal trend that can cause a loss of metallurgical integrity and properties, and metal-to-metal contact on load bearing surfaces
Grease Degradation	High temperatures and increased grease oxidation rate	Grease hardens and becomes ineffective in providing proper lubrication
Misalignment	Wear groove on the axle journal	Causes roller race edge loading and geometric stress concentrations
Spall Initiation	Thin films, metal-to-metal contact, and geometric stress concentrations	Spalling generates metal debris and bearing starts to generate vibration
Vibration	Same as above for spall initiation	Spalling with the loss of bearing raceway surface integrity
Bearing Thermal	Excess heat, debris damage and inadequate lubrication	Bearing seizes and loses material properties required to properly function

Fig. 9 A possible failure process from cone creep.

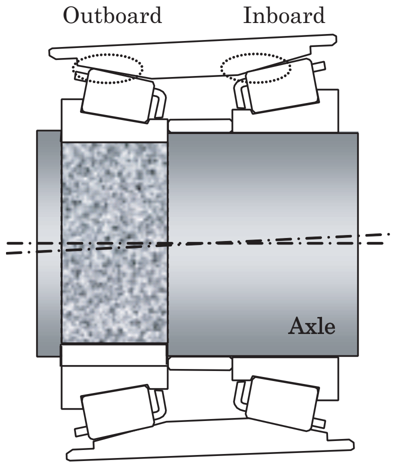


Fig. 10 Concentrated loading caused by the missaraiment

reduction in the axle OD due to wear and thermal growth in the cone bore, leading to the increase in the gap between them. As the gap increases, the cone motion rate rises. The gap increase also allows the bearing misalignment to increase. This results in a concentrated loading condition inside the bearing as shown in Fig. 10, which can initiate spalling on the cup race and roller due to high concentrated localized stress, often called "geometric stress concentration" type spalling. As a result, vibration and noise levels increase.

In the meantime, wear products from the axle, cone and backing spacer coupled with the bearing temperature rise cause grease contamination and oxidation, or "carbonization". The deterioration in the lubrication results in metal-to-metal contact between cone, cup and rollers from a loss of the oil film on these contact surfaces. This can cause a rapid temperature rise on a local area of the contact surface, so that material properties such as microstructure and hardness can change.

It would be predicted that further progress of cone creep to cone "spinning" could result in severe damage to the bearing and the axle/cone interface due to heat generation. Furthermore, it has to be considered that there are some differences in operating condition between laboratory test and an actual revenue service. Railroad axle journal bearings experience axle deflection and variable loading including impact loads under variable speed. Therefore, it is recommended that the effect of the cone creep failure process in relation to actual operating conditions be investigated.

4. Conclusions

A cone creep simulation test using a full-scale railroad bearing was conducted in a laboratory in order to obtain information which can be instrumental in understanding and clarifying the bearing failure process starting from cone creep. Test results indicate that rapid temperature increases are not observed at the initiation of cone creep and that the increase in bearing temperature is not directly related to the rate of cone creep. However, the progression of the cone creep to cone spinning generated a more accelerated rate of axle wear and a loss of the cone fit on the axle, leading to an increase in the gap at cone/axle interface. Consequently, the bearing temperature increased in connection with internal damage and deterioration such as grease oxidation and bearing misalignment.

Although no temperature rise is observed after an initiation of cone creep, cone creep phenomena leading to serious cone spinning on the axle can result in a rapid temperature rise leading to bearing burn-off. It is critically important to maintain the proper interference fits between the bearing cones and the axle journal. Additionally, particularly in critical high-speed and passenger applications, it is recommended that a reliable onboard temperature monitoring system be utilized to prevent a potential bearing burn off condition or situation.

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References

1) Sneed W.H., et al. "On-board real-time railroad bearing defect detection and monitoring", ASME RTD-Vol.14, pp.149-153, 1998
2) Anderson G.B., et al. "Acoustic Identification of a Spun Cone Roller Bearing Defect", ASME RTD-Vol.13, pp.19-25, 1997
3) Anderson G.B., et al. "Burn-off Simulation of a Railroad Bearing", ASME RTD-Vol.12, pp.87-96, 1996
4) Fec M.C. & Anderson G.B. "Preventive medicine for bearings", RAILWAY AGE, pp.67-73, 1995
5) Kesler J.K., et al. "Measurement of the rotational slippage of the inner race of railroad bearings", SPIE Vol. 2458, pp.128-136, 1995
6) Leedham R.C. "Mechanistic aspects of bearing burn-off", ASME RTD-Vol.5, pp.175-182, 1992