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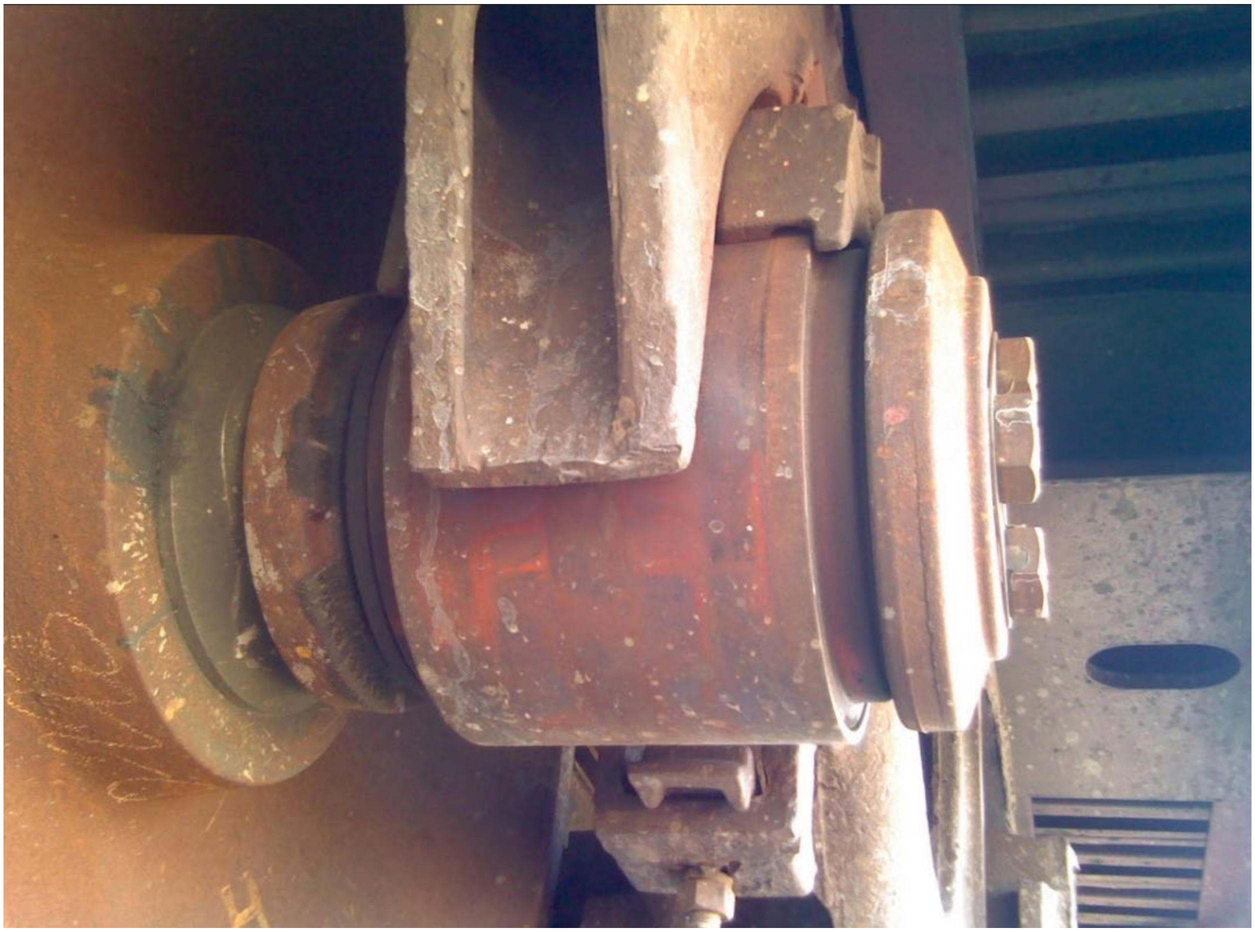
Technologies and Testing to Prevent Water Ingress in Railroad Bearings



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Bearing degradation and defects can result in a bearing being removed from service before the end of its normal service life or possible bearing failure, causing service disruption or even derailment. Water damage is the leading cause of premature bearing failure; therefore, preventing this damage is of primary concern to ensure safety in rail operations. Between 2018 and 2022, researchers at Transportation Technology Center, Inc., using the resources at both the Transportation Technology Center and an outside lab, investigated various seal types for their ability to prevent water (in the form of vapor and spray) from penetrating and damaging railway bearings over their service life and in different service parameters. A discussion of the related phenomenon of fretting corrosion and potential methods to prevent water ingress is also included.

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1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

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1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

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METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

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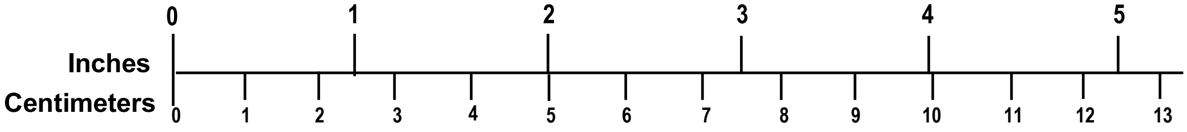

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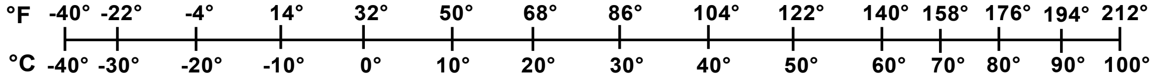

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Executive Summary

Bearing degradation and defects can result in a bearing being removed from service before the end of its normal service life or possible bearing failure, causing service disruption or even derailment. Water damage is the leading cause of premature bearing failure; therefore, preventing this damage is of primary concern to ensure safety in rail operations. Between 2018 and 2022, researchers at Transportation Technology Center, Inc., using the resources at both the Transportation Technology Center and an outside lab, investigated various seal types for their ability to prevent water (in the form of vapor and spray) from penetrating and damaging railway bearings over their service life and in different service parameters.

TTCI divided this research into three main tasks. The first task explored how rubbing lip seals and frictionless seals performed in watertightness against direct water spray over their service life. The second task examined how rubbing lip seals and frictionless seals performed in watertightness against environmental changes. The final task investigated the related phenomenon of fretting corrosion, as well as potential methods to prevent it.

The first task included two tests. The first test used bearings selected from revenue service at different periods in their service life and subjected them to water spray tests in the laboratory. After the water spray test, the water weight percentage of the grease weight for the frictionless seals at the end of their service life was less than 0.5 percent. Researchers then conducted a second test to examine the rubbing lip seals throughout their service life. After the water spray test, the water weight percentage of the grease weight for two of the rubbing lip seals at the end of their service life was more than 0.5 percent, with an average weight of 4.26 percent. All tested periods of the bearings' service life had a mean water weight greater than 0.5 percent of the grease weight. Future tests could be conducted to explore what effect the removal and installation of bearings would have on rubbing lip seals. These tests could also explore the first year in the service life of a bearing to understand if seal wear is involved in the loss of water tightness.

The second task included bearings undergoing temperature fluctuations at high humidity in an environmental chamber. After approximately 250 cycles, the frictionless seal bearings and rubbing lip seal bearings showed no evidence of water penetration through the seal or seal grease on either bearing type.

The last task explored fretting corrosion. Fretting occurs when two in-contact surfaces, intended to be stationary, have a small-amplitude cyclic motion relative to each other, often caused by external vibration. Fretting corrosion creates damage that looks very similar to water etching on a bearing running surface. Some bearings damaged by fretting corrosion may have been misclassified as having water damage. To test this, researchers induced fretting corrosion on a bearing raceway. The results showed that, for ordinary situations (i.e., shipping, storage, and installation on unloaded wheelsets), vibration alone was not sufficient to induce fretting wear between the rollers and the running surfaces. Even in instances of residual lubrication, the vibration was not enough to allow the surfaces to penetrate the protective film layer up to 120,000 cycles.

Researchers concluded that: (i) vibration alone does not cause fretting; (ii) frictionless seals performed better than rubbing lip seals in the water spray testing; and (iii) there was no evidence of water penetrating through the seal and seal grease on either bearing seal type during the temperature cycling with high humidity testing.

1. Introduction

Bearing degradation and defects can result in a bearing being removed from service before the end of its normal service life or possible bearing failure, causing service disruption or even derailment. According to the Association of American Railroads (AAR) Roller Bearing Inspection Report (MD-11), water damage is the leading cause of premature bearing failure. Therefore, preventing water damage is of primary concern to ensure safety in rail operations. This research, performed between 2018 and 2022 by Transportation Technology Center, Inc. (TTCI) at the Transportation Technology Center (TTC) in Pueblo, CO, and an outside lab, investigated two types of potential damage-causing water penetration (i.e., direct water spray and water vapor caused by environmental elements such as high humidity and temperature changes). Researchers studied the ability of different seal types, over their service life and in different service parameters, to prevent water ingress into railway bearings. A discussion of the related phenomenon of fretting corrosion and potential methods to prevent water ingress is also included.

1.1 Background

Bearing manufacturers have made advancements to ensure the water tightness of railway bearings. These advancements include changes to the bearing seals and bearing grease. Bearing seals have two parts, one attached to the stationary area of the bearing and the other attached to the rotary area of the bearing.

Rubbing lip seals, the current baseline seal used for bearings in North America, prevent water and contaminants from entering the bearing by having both parts physically touching. The advanced seal for railway bearings is a frictionless seal, also called a labyrinth seal, that uses a complex geometry to prevent water ingress. The rotor or stator part of the seal is folded inside the other part of the seal without making contact.

Both seal types also use bearing lubrication grease to prevent water ingress. During its operation, the bearing creates a positive internal pressure that presses the grease to the bearing seal. The grease pushes out through the rotor and stator part of the seal and prevents material from moving in through the seal.

This research project investigated the ability of these different seal types, over their service life and in different service parameters, to prevent water ingress into railway bearings that can cause damage (an extreme example of this damage is seen in Figure 1). Also included is a discussion of the related phenomenon of fretting corrosion and potential methods to prevent it.

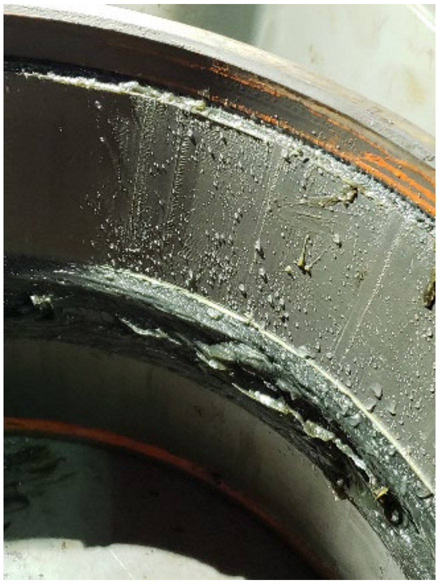


Figure 1. Bearing Cup Running Surface with Water Ingress

1.2 Objectives

The primary objective of this research was to improve safety and reduce bearing related incidents. This objective was met by investigating the following:

- How rubbing lip seals and frictionless seals perform to prevent water ingress on bearings over their service life
- If water ingress will occur in railway bearings due to environmental conditions, such as hot and cold temperature cycles
- Methods to correctly identify fretting corrosion and mitigate it in revenue service

1.3 Overall Approach

The research was divided into three main tasks that investigated the ability of different seal types to prevent water ingress into railway bearings over their service life and in different service parameters. The first task used watertightness tests to explore how rubbing lip seals and frictionless seals perform against direct water spray over their service life. This task used sets of bearings selected from revenue service at different periods in their service life and subjected them to water spray tests in the laboratory. The second task examined how rubbing lip seals and frictionless seals perform against environmental changes using the same watertightness tests. This task used bearings undergoing temperature fluctuations at high humidity in an environmental chamber. The last task explored fretting corrosion. A test was conducted to determine if fretting corrosion could be induced on a bearing raceway. These experiments and research support the objective of improving safety and reducing bearing related incidents in the railroad industry.

1.4 Scope

This research concentrates on freight rail roller bearings in North America, specifically, Class F and K bearings. The seals tested were provided by railroads or bearing manufacturers and are representative of two of the basic types of seals currently in use in revenue service.

1.5 Organization of the Report

- Section 2 reviews the rubbing lip seals and frictionless seals in water tightness tests.
- Section 3 discusses environmental chamber tests on the seals and the effect of temperature fluctuations on bearings regarding water ingress.
- Section 4 reviews the mechanics of fretting corrosion, presents results showing the possible induction of fretting corrosion on a bearing surface and suggests methods to mitigate corrosion damage.
- Section 5 summarizes the research and discusses future work.

2. Water Tightness Test of Roller Bearing Seals

Two experiments were performed in the first task. One experiment assessed the water tightness of the bearing seals at the end of their service life using a water spray applied directly to the seal to determine its ability to resist water flow into the bearing. This test used bearings with rubbing lip seals and bearings with frictionless seals. The second experiment examined the rubbing lip seals throughout their service life by conducting the water spray test on bearings removed from service at different stages of wear.

2.1 Water Tightness Spray Testing Method

The first experiment used the AAR water spray test [1] to determine the watertightness of the bearing seals over the service life of the bearing. This water spray test is normally used to qualify a new bearing seal for revenue service. Researchers adapted this test to explore the watertightness of the seals after they gained in-service wear.

2.1.1 AAR Water Spray Test

The water spray test was conducted on eight bearings, four with frictionless seals and four with rubbing lip seals, and the results were compared to those achieved with new seals. This test was used to determine if there are differences in performance between the rubbing lip and frictionless seals, as well as to indicate differences in performance between used and new seals. Most importantly, the test demonstrated if the performance of both types of seals degrades over time.

After the initial direct spray test, a second test was conducted using 16 bearings with rubbing lip seals. These bearings were chosen from different stages of service life and the results of this test were compared to the established standards.

The testing was completed on a specialized bearing rig at an offsite laboratory. The rig ran the bearings at 60 mph for 21 hours while 2 nozzles sprayed the inboard and outboard seals of each bearing at a rate of 0.8 gallons per minute at 100 psi. The test measured the accumulated water weight in each bearing to determine if there were performance differences between the rubbing lip seals at different stages of service life. The water weight allowed to penetrate the seal before it failed the test was limited to 0.5 percent of the grease weight in the bearing [1].

2.1.2 Compare and Contrast to UIC Water Tightness Test

The International Union of Railways (UIC) employs a standard to authorize new bearing seals for service. Part of this standard is a water tightness test similar to the AAR test. As in the AAR test, there is no load applied to the bearing for the duration of the test. A rig test consists of a direct water spray, lasting seven hours and using seven different speeds (0–350 km/h; 0–217.5 mph). This test runs for a much shorter duration than the AAR test. Two additional key differences in the tests include that the bearing is tested with little or no grease and that the threshold for failure is measured by any water penetration into the bearing [9]. These test differences reflect the operational and mechanical differences (e.g., speed, load, exposure to elements, etc.) in the European and North American rail industry.

2.2 Initial Test of End of Service Life Bearing Seals

Eight worn-in bearings, four with rubbing lip seals and four with frictionless seals, underwent the water spray test. These bearings were removed at the end of their service life due to worn wheels but showed no visible bearing damage or defects once opened. These bearings were removed in the fourth quarter of 2018.

The water spray test was used on these bearings to determine if there is a watertightness difference in performance between the rubbing lip and frictionless seals, as well as to indicate differences in performance between used and new seals. This test investigates if the performance of both types of seals degrades over time.

For testing efficiency, it was assumed that new seals of these types would pass the water spray test (weight of free water after the test would be below 0.5 percent of the grease weight in the bearing), as they are AAR approved for use in revenue service.

The four bearings with frictionless seals passed the water ingress test. The highest water weight measured was 0.42 percent of the grease weight and the lowest water weight was 0 percent of the grease weight.

Two of the bearings with rubbing lip seals failed the water ingress test. All four bearings with rubbing lip seals had an average free water weight accumulation of 4.26 percent of the grease weight. The highest water weight measured was 13.59 percent of the grease weight and the lowest water weight measured was 0 percent of the grease weight. Figure 2 shows the mean free water weight of these bearings as a percentage of the grease weight.

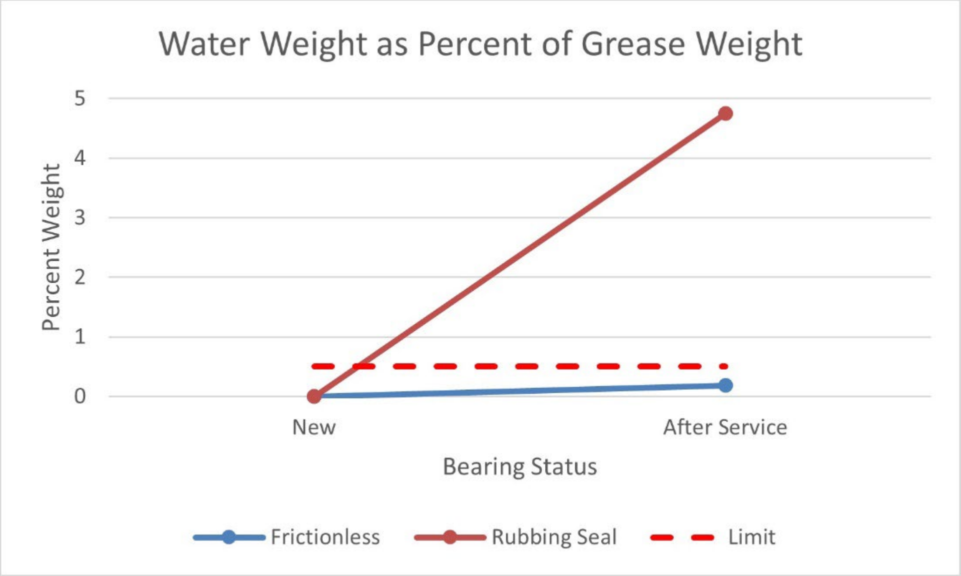


Figure 2. Water Weight as Percent of Grease Weight in Test Bearings

Based on these results, the rubbing lip seals appear less likely to prevent water ingress at the end of their normal service life. Therefore, it was decided to test a larger set of bearings to investigate this finding. The bearing seals were tested at different points in their service life to determine if the seals degraded during performance and, if so, determine the period of wear.

2.3 Sample Selection for Expanded Test of Bearing Seals

In the previous test, bearing seals were chosen at the end of their service life, based on the standard for wheelset removal for wheel wear. Railway bearings are greased for life, but the seals are only used once and are replaced each time the bearing is removed from the axle. Once the wheel is worn, the bearing is removed and the seal replaced, therefore, it can be assumed that the service life of the bearing seal is related to the wear of the bearing and the wheel.

Gross ton miles (GTM), a unit of measure common in the rail industry, is one of the best metrics used as a proxy for indexing wear on the bearing. However, this measurement is impractical when selecting samples, as it is frequently unavailable to researchers. As an alternative, researchers developed a method that could be used by the operator in the wheel shop to identify potential bearings for the test using the proxy criteria of wheel wear and time in service. Based on the experience of the wheel shop and research experience, it was assumed that wheels in continuous service will last five years and that the rim wear of a wheel is linearly proportional to GTM. When collecting samples for this test, it was also assumed that the bearing wear is nearly equal to the wheel wear, as the bearings and the wheels experience the same load and mileage.

Using the time in service (measured in years) and the wheel rim thickness, (measured in inches), researchers developed criteria for five service life categories. Table 1 shows the five categories and their criteria, as well as the number of samples collected. The thickness was divided into categories by tenths of an inch but converted to the closest 1/16th of an inch for ease of measurement. The minimum rim thickness of a new H-36 wheel is 1 1/2 inch, and a wheel must be pulled from service when the rim thickness is less than 1 inch [2].

Table 1. Bearing Seal Service Life Category Based on Wheel Rim Thickness and Time in Service

Category	Years Since Installation	Wheel Rim Thickness	Number of Samples Collected
1	Equal to or greater than 1 year	Less than 1 1/2 inch	2
2	Equal to or greater than 2 years	Less than 1 7/16 inch	4
3	Equal to or greater than 3 years	Less than 1 5/16 inch	4
4	Equal to or greater than 4 years	Less than 1 1/4 inch	2
5 (end of service life)	Less than or equal to 5 years	Less than 1 1/8 inch	4

A bearing seal is categorized for service life based on both the years since installation and the wheel rim thickness measurements, starting from Category 5 and working backward to Category 1. Once these samples were collected, they were inspected for signs of defects or damage before undergoing the AAR water spray test.

Statistically, the water spray test data could be affected by the low number of samples in each category; this was considered when creating the test. It was decided that this sample size was acceptable because it matches the sample size required by the AAR for bearing seal qualification.

2.4 Test of Bearing Seals Over Their Service Life

After the water spray test was performed, the water weight was measured. Table 2 shows the water weight as a percentage of the grease weight for each sample in each category.

Table 2. Water Weight as Percent of Grease Weight in Test Bearings

Bearing	Category	Bearing Water Weight %
1	1	109.75
2	1	4.73
3	2	11.29
4	2	0.00
5	2	21.04
6	2	19.21
7	3	15.41
8	3	0.13
9	3	4.82
10	3	31.01
11	4	9.40
12	4	8.16
13	5	14.69
14	5	0.08
15	5	28.18
16	5	8.91

Only three of the 16 bearings tested finished the water spray test with a water weight to grease weight percentage of less than 0.5. Figure 3 shows the mean water weight percentage of the grease weight for each category of bearing service.

The results of this test were unexpected. Not only are the means of the water weight high in each category, but they are also similar for most categories (the outlier of Category 1 may be related to the small sample size of that category). If the rubbing lip bearing seals lost their ability to remain watertight over their service life, one would expect to see an increase in the weight of water as the service life period increased or a shift in means at that service life period. A loss of watertightness may occur before the first investigation period, and as a result the degradation of the seals does not increase the water weight allowed in the bearing over time.

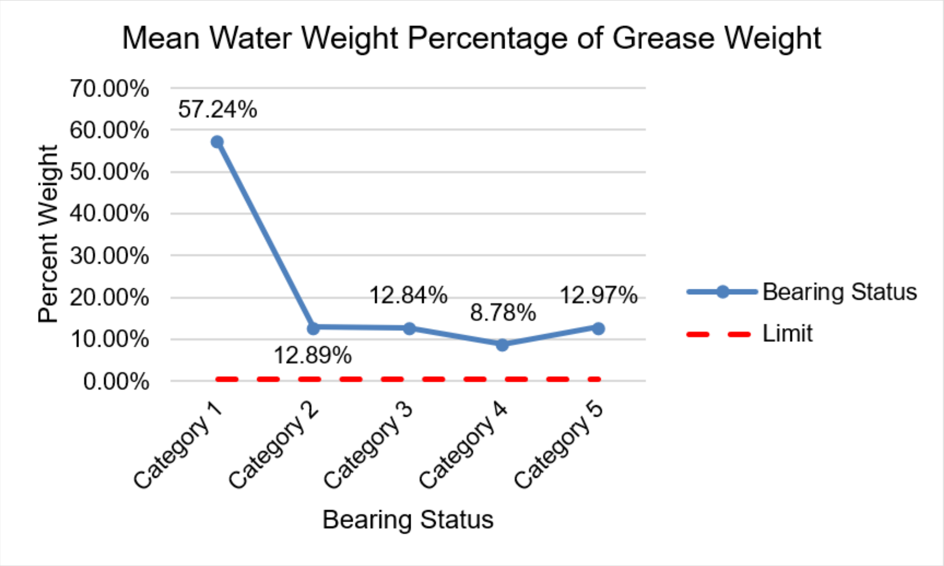


Figure 3. Mean Water Weight Percentage of Grease Weight in Bearings Over Their Service Life

One potential, yet unlikely, possibility is that removing and installing each bearing for the test would affect the spacing of the rotor and stator parts of the rubbing lip seals. However, as stated above, the bearings and seals are visually inspected for damage before and after the test. The bearing press on force is monitored to ensure a proper seating of the bearing on the test axle. The bearings are checked for proper lateral movement after installation. The grease was not affected in the removal and installation of the bearing, so its function in the seal was maintained. Future testing could investigate the rubbing lip seal contact and possible changes before and after the removal and installation of the bearings.

2.5 Discussion of the Water Spray Test on Frictionless and Rubbing Lip Seals

At the end of their service life, the water weight percentage of the grease weight for the frictionless seals was less than 0.5 percent after the water spray test. For two of the rubbing lip seals at the end of their service life, the water weight percentage of the grease weight was more than 0.5 percent after the water spray test, with an average of 4.26 percent. A second test was conducted to examine the rubbing lip seals throughout their service life. All tested periods of the bearings' service life had a mean water weight greater than 0.5 percent of the grease weight. If the loss of watertightness is related to wear of the seal, this loss must occur at a service period before those tested.

Future tests could be conducted to explore the effect of the removal and installation of bearings on rubbing lip seals. These tests could also explore earlier time periods in the service life of a bearing to understand if seal wear is involved in the loss of water tightness.

3. Environmental Chamber Test

In addition to direct water spray (e.g., rain and flooding) water ingress may also occur through high humidity levels and temperature cycles, potentially as water vapor in the air penetrates the seal and degrades the grease. Testing seals during various environmental conditions could indicate if water ingress occurs through the testing processes and identify potential avenues of research to prevent bearing degradation for equipment that is exposed to these conditions.

3.1 Chamber Testing Method

A test was conducted to determine if it is possible to induce water ingress on rubbing lip seals and frictionless seals through varied environmental conditions, such as hot and cold temperature cycles combined with high humidity. Eight bearings, four with rubbing lip seals and four with frictionless seals, were put through hot and cold temperature cycles at high humidity in the bearing test lab to determine if this is a plausible mode of water ingress. These bearings were examined for signs of water accumulation at the end of the test.

The cycles started at an ambient temperature of 105°F and was held until the bearing reached the same temperature. From test start through completion the relative humidity was held at 70 percent. The ambient temperature was then dropped to 32°F. As the temperature dropped, the moisture in the air condensed onto the surfaces of the bearings. The lower temperature was held until the bearing surface reached the 32 degrees. The water that condensed on the bearing surface then began to freeze. The cycle was then repeated, with the temperature again rising to 105°F and the relative humidity held at 70 percent up to that temperature, allowing the water to evaporate again. Figure 4 shows the bearings in the environmental chamber.

Figure 4. Bearings in Environmental Chamber

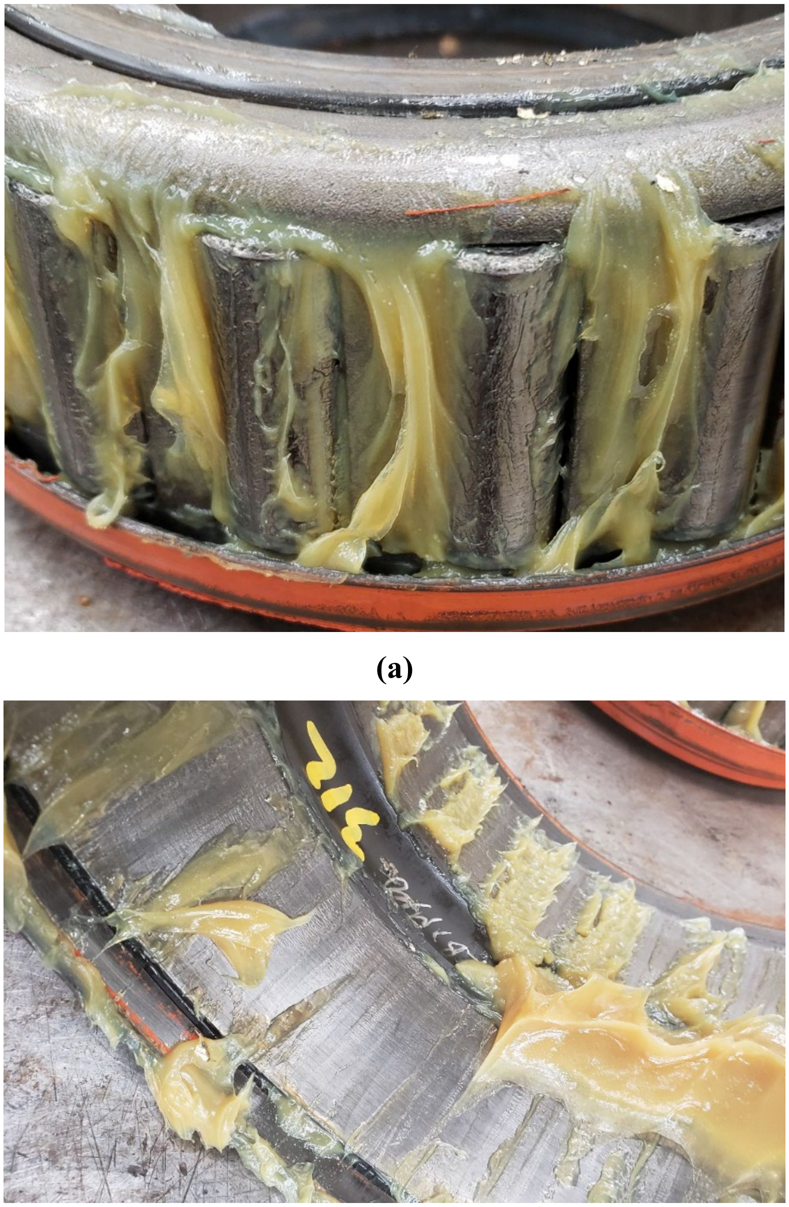
Each test ran for approximately 250 cycles. At the halfway point in the test, two bearings of each seal type were removed and examined. The remaining bearings were removed at the end of the test.

3.2 Chamber Testing Results and Discussion

After approximately 125 temperature cycles, two of the frictionless seal bearings and two of the rubbing lip seal bearings were removed from the test chamber. The effect of humidity on many of the bearing components was evident; the exterior surfaces of the bearings, including the cups, backing rings, end caps, and end cap bolts had corroded. This corrosion is shown in Figure 5. While there was evidence of water on the bearing seals, there was no evidence of water penetrating through the seal and seal grease on either bearing seal type.

Figure 5. Corrosion on Bearing Surfaces

Similarly, after approximately 250 cycles, the remaining two frictionless seal bearings and two rubbing lip seal bearings were removed from the chamber. The corrosion was evident on these bearings as well, but again there was no evidence of water penetrating through the seal and seal grease on either bearing type. The resulting effects on the frictionless seal bearings and rubbing lip seal bearings are shown in Figure 6 and Figure 7, respectively.



(a)

(b)

Figure 6. Frictionless Seal Bearing at the End of Environmental Test, (a) cone and (b) cup

Figure 7. Rubbing Lip Seal Bearing at the End of Environmental Test

3.3 Potential Storage Problems of Railway Bearings

These bearings were tested without being installed on an axle or a stub axle, thereby leaving the interior section of the bearing, normally in contact with the axle, exposed to the environment of the chamber. The joints between the center ring and cone assemblies, as well as the joints between the wear rings and the cone assemblies, are areas of potential water ingress. When preparing for this test, different methods of sealing these joints were attempted. Ultimately, the team determined that the best method was sealing the joints with silicone caulking, as other methods left open gaps in the joints, allowing the water vapor to penetrate the bearing. This water ingress caused corrosion on the surfaces inside the bearings near the joints. This finding signifies the importance of the proper storage of bearings before they are installed on the wheelsets. Most bearings in the industry are shipped inside plastic wrapping to protect against moisture. However, moisture could become an issue for bearings stored outside of a climate-controlled area.

4. Fretting Corrosion Investigation

This research also explored the occurrence of fretting corrosion related to water damage. Fretting corrosion creates damage that appears very similar to water etching on a bearing running surface. Recent research in bearing grease analysis has shown that some bearings identified as having "water-etch" failure modes did not contain excessive moisture in the grease. The failure mode of these bearings may have been misclassified as water damage when it was actually fretting corrosion.

To understand the related failure mode of fretting corrosion, researchers conducted a literature review of the current state-of-the-art testing and mitigation of the fretting corrosion mechanism in bearings. A shaker table test was conducted on two bearings to attempt to induce fretting wear and corrosion on stationary bearings through vibration. Review of Current Research on Fretting Corrosion

Fretting occurs when two in-contact surfaces that are intended to be stationary have a small amplitude cyclic motion relative to each other, often caused by external vibration [11], [3], [4], [15], [8], [6], [12], [5], [9], [13]. Wear develops when surfaces in contact experience reciprocating sliding motion during low amplitude over many cycles [5]. Fretting can occur with displacement amplitudes as low as one micrometer [13], not only with a linear sliding motion, but also with a rotational motion [4]. One characteristic of fretting is the formation of oxide debris [10]. Fretting can be accompanied by corrosion when oxidation occurs on the worn material. In steel, this corrosion produces a dark red debris (alpha Fe_2O_3) that appears similar to damage caused by water ingress into the bearing [6], [7].

Bearings that undergo any type of oscillation or vibration will experience fretting if the raceway components are in contact. Examples of these types of conditions occur when rail equipment are located on a siding near passing trains or when rail equipment rock due to strong winds. These conditions could lead to fretting corrosion if surfaces are in contact and lubrication has failed or has been bypassed. Bearings can also be subjected to these forces in both storage and transportation [3], [4].

The movement of the contacting surfaces in relation to each other causes the raceway material to wear away, creating debris [11]. This debris and the newly revealed surface will then corrode [11]. The wear depth will be correlated to the friction, normal force, and displacement [3]. Depending on the force and displacement, the fretting is categorized into different regimes. The first is the stick regime, in which there is no relative motion between the surfaces. The second is the partial slip regime, in which there is motion only at the edges of the contact area. This regime is associated with cracking. The third is the slip regime, in which the surfaces move and wear on each other [15], [13].

The fretting process progresses in three stages. During the first stage, the asperities of the two surfaces create adhesion and wear away as particles. These particles oxidize during the second stage. The third stage is the creation of an oxide layer and steady state wear [15], [10]. The oxide particle formation requires the presence of oxygen at the surface [4].

An oxide layer forms from the wear debris [12]. These oxides are usually harder than the surface material [11]. The behavior of this oxide layer factors in fretting wear [12] and can either act as an abrasive or a protectant [12]. The difference in behavior can be attributed to the displacement magnitude between the surfaces. If the displacement is large, the oxides will move out of the contact area and act as an abrasive across the surfaces. At smaller displacement levels, the oxides can stay in the contact area [12], [14], [7]. Another factor at play is the frequency of the vibration. At high frequencies, the contact temperature increases, and the oxide adheres to the contact area, preventing further wear [4].

Fretting wear diminishes over time as the oxides created provide a layer between the two surfaces; in typical applications the fretting damage ceases to progress into major material loss [14]. However, bearing rolling surfaces are a special case. These surfaces are stationary during the fretting process, but when the equipment is in motion, the surfaces roll against each other. Therefore, an oxide layer created in the raceway could easily be removed when the bearing rolls, creating an area for crack or spall formation.

Methods are available to mitigate the damage produced by fretting. One method would be to decrease the vibration acceleration to decrease material wear [3], [6]. Another method is to increase the normal load on the bearing [3], [4], [6]. Some research indicates that changes in the design or surface treatments will alleviate fretting wear and corrosion [5], but a more straightforward method is to use a lubricant to create a film between the two surfaces [11], [4], [6], [5]. Because fretting wear occurs after many cycles of relative motion, by rotating the bearing frequently, the surfaces in contact change, limiting surface damage [6].

4.1 Shaker Table Testing Method, Results and Future Work

To further understand fretting corrosion, researchers attempted to induce fretting wear in two bearings using a shaker table test. This test induced vibrations on two class K bearings to determine the possibility of revenue service caused fretting wear and corrosion. The bearings were installed on the shaker table without seals with the bearing cup secured to the tabletop. This setup allowed the cone assemblies to move freely. The contact area under observation was between the rollers and cup raceway. The test setup is shown in Figure 8.

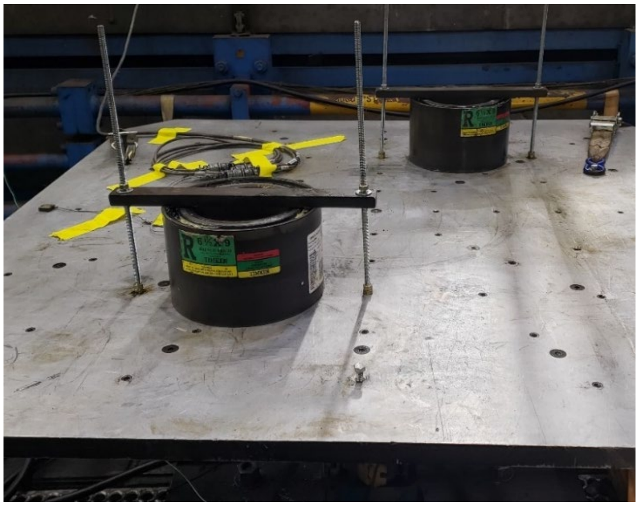


Figure 8. Shaker Table Test Setup

The shaker table was operated at 12 Hz with a 2mm displacement from zero to peak; this corresponds to 1.15 G zero to peak (0.813 G rms). This displacement distance means that the roller surface and cup raceway surface are categorized into the gross slip fretting regime. Runs were made at 20,000 cycles, 40,000 cycles, and 120,000 cycles. The first two test runs were made with the bearing in the "as assembled" operational condition, i.e., fully greased. The bearing was spun sufficiently to ensure the grease was fully distributed across the bearing components. After the second test, it became apparent that vibration alone was insufficient to create fretting conditions in the bearing. The rollers could not penetrate the protective film of the grease and contact the cup running surface. Figure 9 shows the cup running surface after the first two test runs.

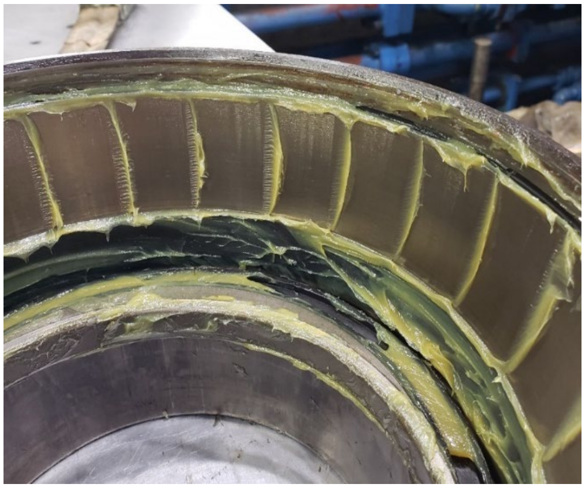


Figure 9. Bearing Running Surface After Second Test

Before the third test run, the grease was physically removed, but not washed away, from the running surfaces. This was done to avoid introducing contaminants to the surface and avoid the unrealistic industry application of a bearing completely without lubrication. Once again, vibration was not sufficient to induce fretting wear on the roller or the raceway surfaces, even after 125,000 cycles, because the roller was not able to penetrate the residual film of the lubricant. Figure 10 shows the running surface after the last test (streaks on the surface are created by the overhead lights).

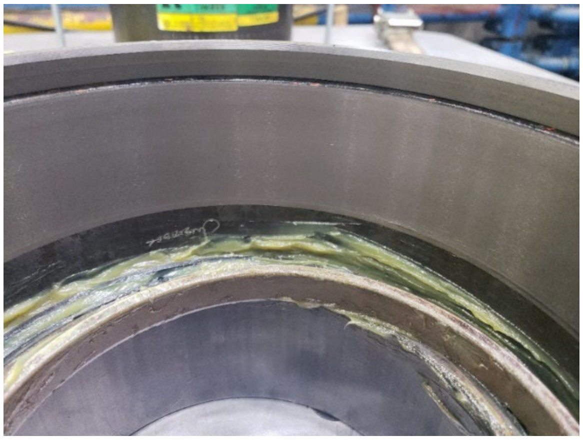


Figure 10. Bearing Running Surface After Last Test

These tests show that for ordinary situations, such as shipping, storage, and installation on unloaded wheelsets, vibration alone is not sufficient to induce fretting wear between the rollers and the running surfaces. Even if lubrication is only residual, vibration is not sufficient to allow the surfaces to penetrate the protective film layer up to 120,000 cycles.

Future research could concentrate on the condition of the grease that would allow metal-on-metal contact in the bearing load zones. The experiment could focus on grease in different states of wear or decay to determine the level of grease degradation that would be conducive to fretting. Testing without grease to understand the theory of fretting wear would be redundant of the research already performed. This research seeks to understand the conditions that lead to fretting in the system of components as found in industry service, including the amount of bearing lubricant. The research could also be expanded to include different load conditions to determine if increased normal pressure will create conditions favorable to fretting.

5. Conclusion

This research was divided into three main tests. The first test explored how rubbing lip seals and frictionless seals performed against direct water spray over their service life in watertightness tests. This experiment took sets of bearings selected from revenue service at different periods in their service life and subjected them to water spray tests in the laboratory. The water weight percentage of the grease weight of the frictionless seals at the end of their service life was less than 0.5 percent after the water spray test. Two of the rubbing lip seals at the end of their service life had more than 0.5 percent water weight as a percent of the grease weight after the water spray test, with an average weight of 4.26 percent. A second test was conducted to examine the rubbing lip seals through their service life. All tested periods of the bearings' service life had a mean water weight greater than 0.5 percent of the grease weight. Future tests could be conducted to explore the effect of removal and installation of bearings on rubbing lip seals. These tests could also explore earlier time periods in the service life of a bearing to understand the effects caused by seal wear in relation to the loss of water tightness.

The second task examined how rubbing lip seals and frictionless seals performed in watertightness against environmental changes. This experiment used bearings in an environmental chamber undergoing temperature fluctuations at high humidity. After approximately 250 cycles, the frictionless seal bearings and rubbing lip seal bearings showed no evidence of water penetrating the seal and seal grease on either bearing type.

Finally, a test was conducted to induce fretting corrosion on a bearing raceway. This test showed that for ordinary situations, such as shipping, storage, and installation on unloaded wheelsets, vibration alone was not sufficient to induce fretting wear between the rollers and the running surfaces. Even if the lubrication was only residual, the vibration was not enough to allow the surfaces to penetrate the protective film layer up to 120,000 cycles.

The overall conclusions of this research project include:

i. Vibration alone does not cause fretting.
ii. Frictionless seals performed better than rubbing lip seals in the water spray testing with respect to water weight percentage to grease weight.
iii. There was no evidence of water penetrating through the seal and seal grease on either bearing seal type during the temperature cycling with high humidity testing.

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Abbreviations and Acronyms

ACRONYM	**DEFINITION**
AAR	Association of American Railroads
GTM	Gross Ton Miles
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
UIC	International Union of Railways