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of Transportation
Federal Railroad
Administration

ROLLER BEARING FAILURE MECHANISMS RESEARCH

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16. Abstract

Mechanisms that cause roller bearing failure are not well understood and were the subject of a research program conducted by the Association of American Railroads (AAR), Transportation Test Center, Pueblo, Colorado. The program was funded by the Federal Railroad Administration under Task Order 45. Additional support for the program was provided by Brenco Incorporated, Servo Corporation of America, Timken Company and RASTECH. The program included three separate tests: (1) Roller Bearing Failure Mechanisms, (2) Cone Bore Growth, and (3) Raceway Defect Growth Rate.

The Roller Bearing Failure Mechanisms test results demonstrated that bearings with grooved axle journal defects develop measurable temperature gradients across the cup surface, which can be detected using wayside Hot Bearing Detector systems configured to scan both the inboard and outboard bearing raceways to identify wheel sets with this defect. Audible acoustic emissions generated by bearings having this defect did not generate any Acoustic Bearing Detector (ABD) system alarms.

The Cone Bore Growth test results demonstrated that while the initial rate of cone bore growth is higher for bearings having a 0.0050-inch interference fit than for bearings having a 0.0025-inch interference fit, the rate of bore growth slows significantly with accumulated mileage. The interference fit of bearings with an initial interference fit of 0.0050 inch remained near the maximum allowed by current AAR specifications over the 20,000 mile test.

The Raceway Defect Growth Rate test results showed that measurable growth occurred for the cup spall defect, while no measurable growth occurred for the cup Brinnel and cone spall defects during the 20,000 mile test. The ABD system consistently identified the bearing with the cup Brinnel as defective, but did not consistently identify the bearings with the cup and cone spalls as defective.

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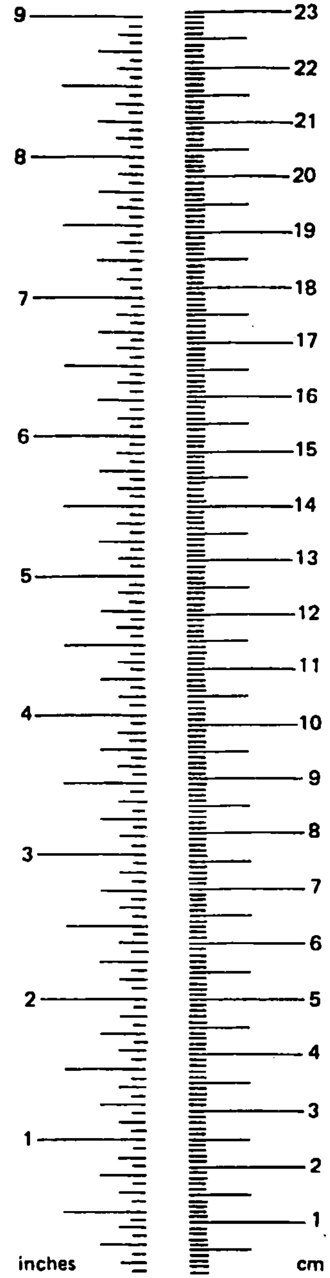
METRIC CONVERSION FACTORS



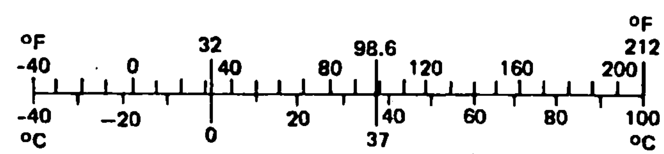
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius° temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

The railroad industry suffers damages to equipment, wayside structures, and lading every year due to derailments caused by roller bearing failure. Mechanisms that cause roller bearing failure are not well understood and were the subject of a research program conducted by the Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado.

The program was funded by the Federal Railroad Administration (FRA) under Task Order 45. Additional support for the program was provided by Brenco Incorporated, Servo Corporation of America, and the Timken Company. RASTECH Incorporated also provided hot bearing detector end cap bolts for each bearing used in the test. The program included three separate on-track tests using actual bearings and cars to define (1) Roller Bearing Failure Mechanisms, (2) Cone Bore Growth, and (3) Raceway Defect Growth Rate.

The following conclusions are supported by the results obtained in each of the tests:

ROLLER BEARING FAILURE MECHANISMS TEST

- Bearings on grooved axle journals developed measurable temperature gradients across the cup surface which can be used by wayside Hot Bearing Detector (HBD) systems designed to scan both the inboard and outboard bearing raceways to identify wheel sets with this defect type.
- A grooved axle condition developed under the outboard cone in bearing D during the test. No defects developed on any of the bearing components.
- The operating temperature of bearing D never exceeded the alarm threshold temperature of 180 F° for the wayside HBD systems.
- A thermal gradient developed across the bearing cup surface of bearing D that was measurable from the wayside using an HBD system designed to intercept radiation from both the inboard and outboard bearing cup raceways.

- Bearing D generated audible acoustic emissions during the test, although the acoustic emissions never generated any Acoustic Bearing Detector (ABD) system alarms.
- A grooved axle condition developed under the inboard cone in bearing H during the test. No defects developed on any of the bearing components.
- The operating temperature of bearing H never exceeded the alarm threshold of the wayside HBD systems.
- Bearing H did not generate any audible acoustic emissions during the test.
- None of the other axles or bearings developed any defects during the test.
- No mechanical failures occurred on the hot bearing detector bolts provided by RASTECH.

CONE BORE GROWTH TEST

- The bearings with a 0.0050-inch interference fit, charged with 44 ounces of grease, exhibited the highest operating temperatures during the test.
- The bearings with a 0.0025-inch interference fit, charged with 24 ounces of grease, exhibited the lowest operating temperatures during the test.
- The 0.0025-inch and 0.0050-inch interference fit bearings, charged with 24 ounces of grease, exhibited lower operating temperatures than similar bearings charged with 44 ounces of grease. The effect of grease content on operating temperature was more pronounced for the bearings with a 0.005-inch interference fit.
- The rate of bore growth for bearings with a 0.0050-inch interference fit slowed significantly with additional mileage.
- The interference fit of bearings with an initial interference fit of 0.0050 inch remained near the maximum allowed by current AAR specifications.

RACEWAY DEFECT GROWTH RATE TEST

- No measurable growth occurred for the cup raceway Brinell defect during the test.
- The ABD system was able to reliably identify the bearing with the cup raceway Brinell as a defective bearing.
- Measurable growth occurred for the cup spall defect during the test.
- Initially, the ABD system was able to reliably identify the bearing with the cup raceway spall as a defective bearing. However after approximately 12,550 miles of operation, the amplitude of the acoustic signal generated by the bearing did not exceed the alarm threshold of the ABD system.
- No measurable growth occurred for the cone raceway spall defect during the test.
- The ABD system did not reliably identify the bearing with the cone raceway spall as a defective bearing. One possible reason for this, offered by the ABD manufacturer, is that the ABD, as currently designed, does not provide coverage for a complete wheel revolution for wheel sets equipped with a 36-inch diameter wheels, and at least one complete wheel revolution is required to detect a defect located on the cone raceway.
- No over-temperature event occurred for any of the bearings used in the test.

The following recommendations are made based on the results obtained in this research program:

- Conduct revenue service tests on a prototype HBD system utilizing rail mounted infrared transducers configured to intercept infrared radiation from both the inboard and outboard cup raceways of each bearing.

- Conduct wheel set and bearing inspections on bearings flagged by the prototype HBD system to develop statistical validation data needed to evaluate the premise that wheel sets with grooved journal defects develop measurable thermal gradients across the bearing cup.
- Conduct additional research to evaluate the capabilities and limitations of the current acoustic defective bearing detection technology.
- Conduct laboratory and on-track tests to determine if acoustic techniques can be reliably used to identify the following conditions:

  (A) Spun cone/grooved journal condition, in the absence of spalling on the rolling contact surfaces, for a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (B) Broken roller element condition in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (C) Broken cage condition in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (D) AAR <u>condemnable cone spall defect</u> in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (E) AAR <u>non-condemnable cone spall defect</u> in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (F) AAR <u>condemnable cup spall defect</u> in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

  (G) AAR <u>non-condemnable cup spall defect</u> in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

(H) AAR condemnable cup Brinell defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

(I) AAR non-condemnable cup Brinell defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- Use the laboratory and on-track test data to identify, develop, and implement improvements in new and currently used acoustic signal processing.
- In the event that acoustic techniques are unable to detect any of the above defective conditions, develop an outline for investigating alternative strategies or techniques for identifying such defective conditions.

Following are the objectives to the research program:

ROLLER BEARING FAILURE MECHANISMS TEST

Investigate the effects of degraded roller bearing cone/axle journal interference fit and end clamp load conditions on the long term (20,000 mile) performance and reliability of 100-ton capacity, AP Class F, roller bearings operating in simulated revenue service conditions under fully loaded 100-ton capacity cars.

CONE BORE GROWTH TEST

Investigate the effect of initial run-in temperature on the rate of bearing cone bore growth using 125-ton capacity, AP Class G, bearings operating in simulated revenue service conditions under fully loaded 125-ton capacity cars.

RACEWAY DEFECT GROWTH RATE TEST

Develop growth rate data for a variety of AAR condemnable roller bearing raceway defects using 100-ton capacity roller, AP Class F bearings operating in simulated revenue service conditions under fully loaded 100-ton capacity cars.

In the Roller Bearing Failure Mechanisms Test, 16 100-ton capacity, AP Class F, bearings having the interference fit/end clamp load combinations listed in the following table were tested under two fully loaded 100-ton capacity open top hopper cars. The cars were operated for 20,000 miles as part of the Heavy Axle Load (HAL) consist on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST).

Roller Bearing Failure Mechanisms Test Bearing Summary

CLAMP	AXLE JOURNAL/CONE INTERFERENCE FIT		
	ZERO	0.75-MIL	1.5-MIL
ZERO		G,H	L,M
10-TON	C,D	I,J	N
SPEC	E,F	K	P,Q
SPEC			R,S

Onboard instrumentation included thermocouples attached to the bearing adapters of each test bearing. Hot bearing detector bolts, manufactured by RASTECH, were installed in the end cap of each bearing to provide a visual indicator in the event of overheating.

Data from three HBD systems and one ABD system was collected to monitor the operating temperature and acoustic emissions of the test bearings.

At the completion of the on-track test, the bearings were inspected for defects, and the cone bore and axle journal dimensions were documented.

In the Cone Bore Growth Test, 16 125-ton capacity, AP Class G, bearings with pre-measured cone bores were provided by Brenco. The bearings were installed under two fully loaded 125-ton capacity open top hopper cars. The cars were operated for 20,000 miles as a part of the HAL consist.

The bearings were equipped with thermocouples to document bearing operating temperature. Hot bearing detector bolts, also manufactured by RASTECH, were installed in the end cap of each bearing to provide a visual indicator in the event of overheating.

At the completion of the on-track test, the bearings were inspected for defects, and the cone bore and axle journal dimensions were documented.

Three 100-ton capacity, AP Class F, bearings were evaluated in the Raceway Defect Growth Rate Test. Each of the test bearings was mounted on a wheel set and installed under a fully loaded 100-ton capacity car. The three cars also were operated as part of the HAL consist on the HTL. The AP Class F bearings completed 20,000 miles of operation during the test. At the completion of the on-track test, the bearings were inspected for defects and the cone bore and axle journal dimensions were documented.

At the completion of the on-track test, the bearings were inspected to document defect growth during the test.

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1.0 INTRODUCTION

The railroad industry suffers damage to equipment, wayside structures, and lading every year due to derailments caused by roller bearing failure. Mechanisms that cause roller bearing failure are not well understood and were the subject of a research program conducted by the Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado.

The program was funded by the Federal Railroad Administration (FRA) under Task Order (T.O.) 45. Additional support for the program was provided by Brenco Incorporated, Harmon Electronics Incorporated, Servo Corporation of America, and the Timken Company. RASTECH Incorporated provided hot bearing detector end cap bolts for each of the bearings evaluated in this program.

1.1 ROLLER BEARING DESIGN

The roller bearing was introduced into freight car use in the United States in 1954. The most common design found in service on today's U.S. railroads is the double row tapered configuration shown in Figure 1. The stationary raceways are located in the outer ring, commonly referred to as the cup. The rotating raceways are located in the roller assemblies, commonly referred to as the cones. The roller elements ride on the rotating raceways, and each roller element is separated from adjacent rollers by the cage assembly. The cone bore diameter is manufactured to be 0.0025- to 0.0045-inch smaller than the axle journal, which results in an interference fit between the cones and the journal, when the bearing is mounted. The two cones are separated by a spacer ring which sets the amount of bearing end-play. The function of the grease seals, which press into the cup and ride on the wear rings, is to retain the bearing lubricant and prevent lubricant contamination. The bearing is held in place on the axle journal by the bearing end cap assembly, which includes three cap screws.

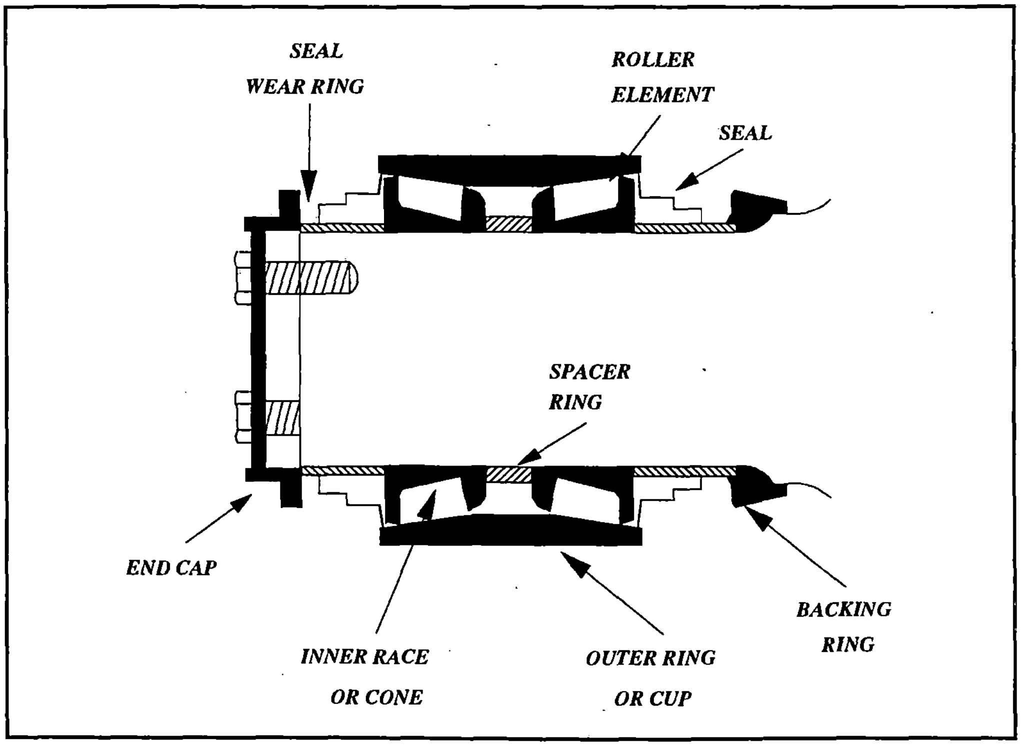

Figure 1. Cross section of a Tapered Roller Bearing (Schematic -- not to scale)

1.2 BEARING DEFECT CLASSIFICATION

Roller bearing inspection and reconditioning practices are subject to the requirements set forth in Volume H - Part II, "Roller Bearing Manual," of the AAR's *Manual of Standards and Recommended Practices*. A brief description of some of the types of bearing defects defined in the "Roller Bearing Manual" and investigated in this research program is provided below.

Brinelling

This defect consists of one or more indentations caused by the roller elements being forced into the surfaces of either raceway, while the bearing was subjected to heavy impact loading. Figure 2 is an example of a Brinelling in a bearing cup raceway.

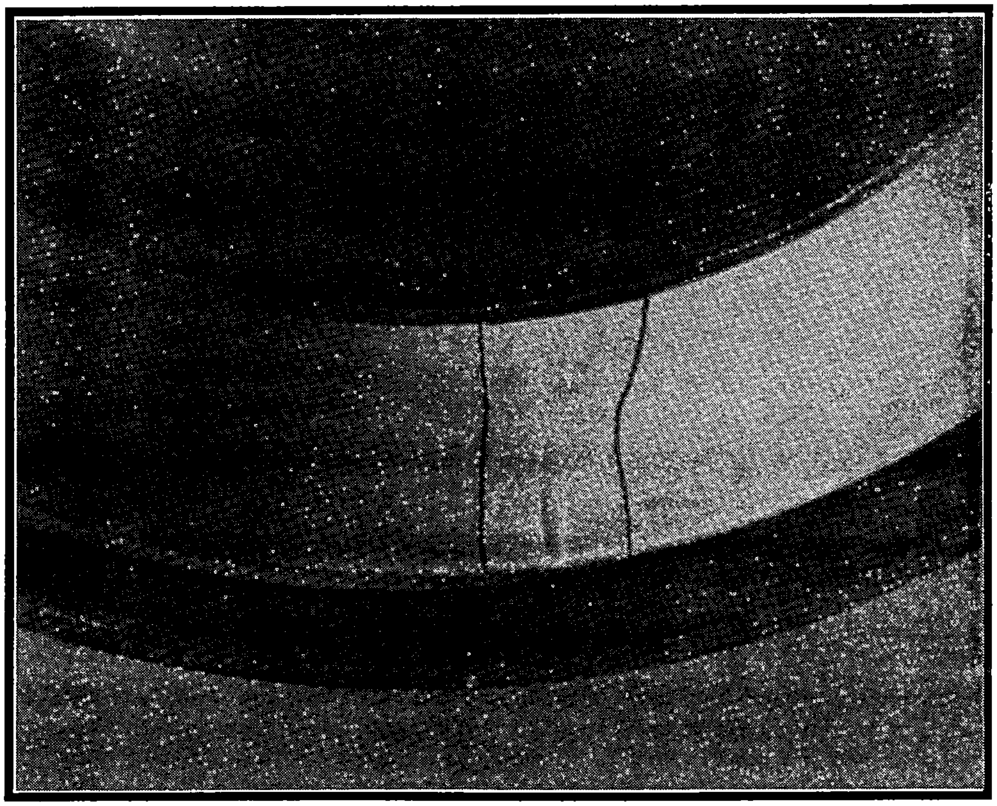

Figure 2. Brinelled Raceway Defect

Spalling

This defect originates as minute cracks which increase in size during cyclic loading and eventually cause metal breakout. The defect occurs on the rolling contact surfaces of the raceways and roller elements. Figure 3 is an example of spalling on a bearing cup raceway.

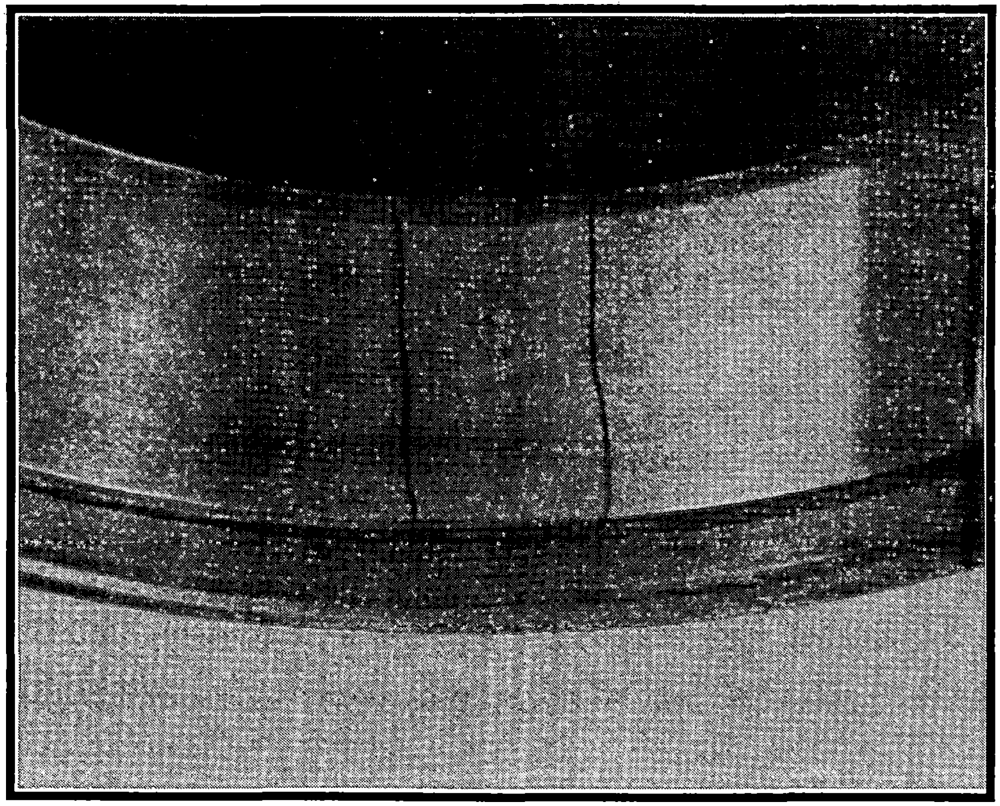

Figure 3. Spalled Raceway Defect

1.3 ROLLER BEARING FAILURE

The two mechanisms believed to cause the majority of catastrophic bearing failures are cone slippage and bearing seizure.

Cone slippage occurs when the interference fit between the cone bore and the axle journal becomes degraded due to a variety of factors. This condition is aggravated by the loss of end clamp load that is caused by the excessive bearing component wear which usually accompanies cone slippage. As the cone(s) slips on the axle, a groove is cut into the journal. As this mode of failure progresses, the depth of the groove in the journal increases resulting in improper loading of the bearing, which can lead to heavy spalling on the rolling contact surfaces.

In the final stages of this failure mode, the operating temperature of the bearing begins to increase rapidly, resulting in softening of the journal which yields under the load of the car. Figure 4 shows a grooved axle journal condition caused by cone slippage.

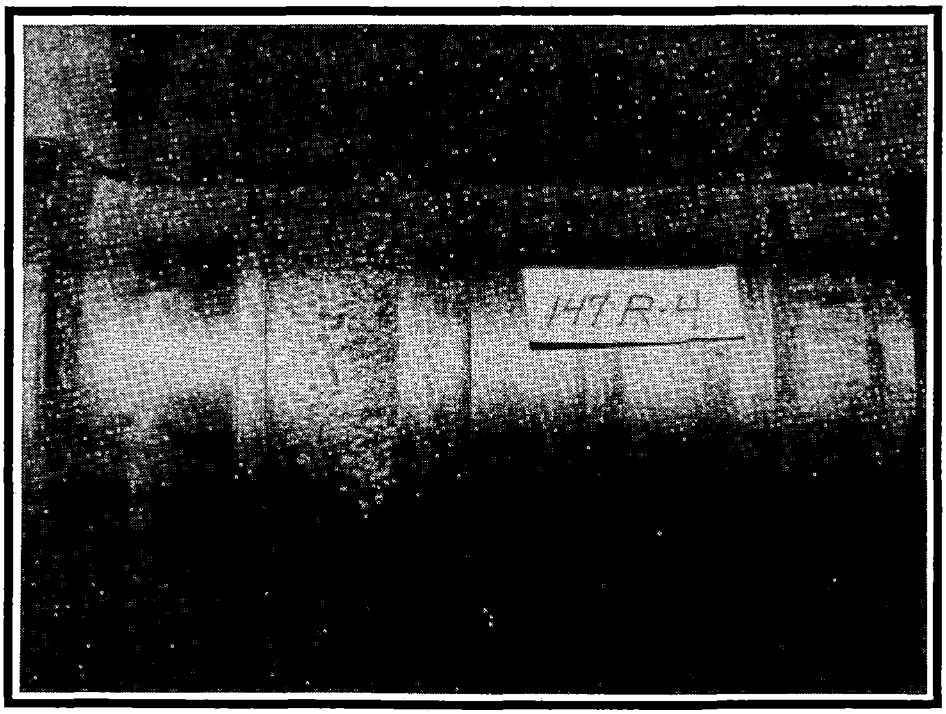

Figure 4. Grooved Axle Journal Defect

Bearing seizure occurs when the rotating and stationary raceways become locked together. This can occur in the final stages of the cone slippage failure mode, or it can occur suddenly and cause catastrophic bearing failure. Potential causes of sudden bearing seizure include fracture of the cage or roller element(s).

1.4 DEFECTIVE BEARING DETECTION

Several methods of identifying defective roller bearings, thereby preventing train derailments due to catastrophic bearing failure, are described below.

HOT BEARING DETECTORS

One way to identify defective bearings is by the use of Hot Bearing Detectors (HBD's). The HBD uses infrared transducers to monitor bearing temperature as the train passes by the detector. The HBD intercepts a portion of the infrared radiation from each bearing and, based on user programmable limits, issues an alarm if the bearing exceeds the preset limit. A typical installation showing the infrared transducer housings is provided in Figure 5.

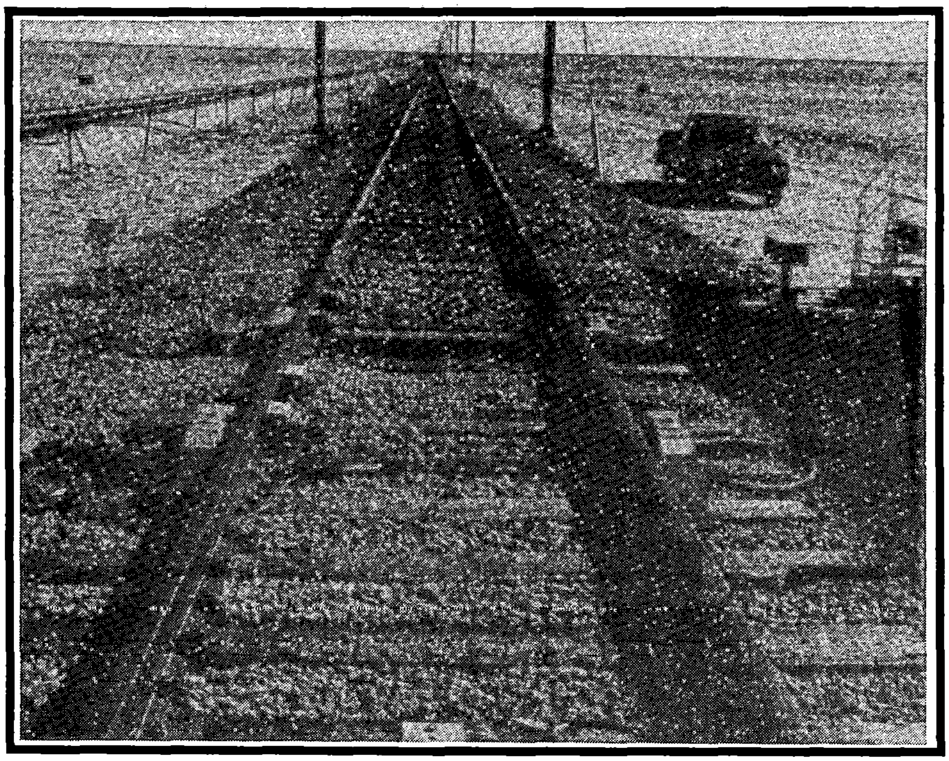

Figure 5. Infrared Transducer Housings of a Wayside HBD Installation

ACOUSTIC BEARING DETECTORS

Acoustic Bearing Detectors (ABD's) also are used to detect defective bearings. Unlike the HBD's, the ABD's are designed to detect bearing flaws before overheated operation occurs. These systems use wayside receivers to monitor acoustic emissions from the bearing as the train passes by the detector. The ABD analyzes the acoustic signal for each bearing and, based on user programmable limits, issues an alarm if a defect is detected. Figure 6 shows the wayside receivers of an ABD system.

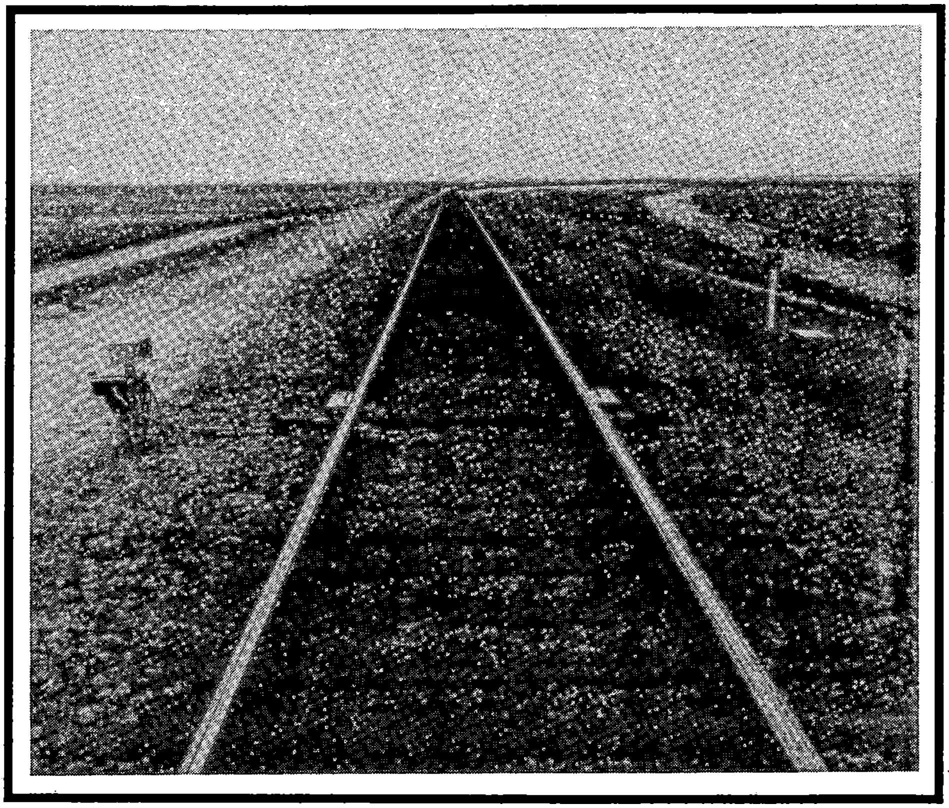

Figure 6. Acoustic Receivers of a Wayside ABD Installation

ONBOARD BEARING MONITORS

Trains carrying sensitive loads and/or passengers are sometimes equipped with Onboard Bearing Monitors (OBM's). OBM's provide protection from bearing failure by continuously monitoring the operating temperature of each bearing and issuing an alarm if any bearing exceeds a preset user programmable limit.

2.0 OBJECTIVES

Three individual tests were conducted to investigate the causes of roller bearing failure in this program. The objective(s) of each test is provided below.

Roller Bearing Failure Mechanisms Test (RBFM)

Further investigate the effects of degraded roller bearing cone/axle journal interference fit and end clamp load conditions on the long term (20,000 mile) performance and reliability of 100-ton capacity, AP Class F, roller bearings operating in simulated revenue service conditions under fully loaded 100-ton capacity cars.

Cone Bore Growth and Bearing Run-in Temperature Test (CBG)

Further investigate the effect of initial run-in temperature on the rate of bearing cone bore growth using 125-ton capacity, AP Class G, bearings operating in simulated revenue service conditions under fully loaded 125-ton capacity cars.

Raceway Defect Growth Rate Test (RDGR)

Develop additional growth rate data for a variety of AAR condemnable roller bearing raceway defects using 100-ton capacity, AP Class F, roller bearings operating in simulated revenue service conditions under fully loaded 100-ton capacity cars.

3.0 PROCEDURES

The procedures developed for each test are described in the following subsections.

3.1 RBFM TEST

Sixteen 100-ton capacity, AP Class F roller bearings that were operated for 17,320 miles on the High Tonnage Loop (HTL) under two fully loaded 100-ton capacity cars as part of the Heavy Axle Load (HAL) consist in previous tests, were operated on the HTL under two fully loaded 100-ton capacity cars for an additional 20,000 miles to further investigate the roller bearing failure process under controlled conditions. Table 1 provides a summary of the bearings used in this test.

Table 1. RBFM Test Bearing Summary

BEARING ID	MFGR	MFG DATE	SERIAL NUMBER	FIT (INCHES)	CLAMP (tons)	LATERAL (inches)
C	Timken	12-80	471222	Zero	10	0.009
D	Brenco	07-88	61113	Zero	10	0.018
E	Timken	09-81	197605	Zero	30	0.010
F	Brenco	07-88	61087	Zero	30	0.011
G	Timken	09-73	55529	0.00075	Zero	0.011
H	Brenco	07-88	61089	0.00075	Zero	0.015
I	Timken	03-77	418299	0.00075	10	0.010
J	Brenco	07-88	61062	0.00075	10	0.014
K	Timken	04-74	50066	0.00075	30	0.007
L	Timken	08-80	438393	0.00150	Zero	0.006
M	Brenco	07-88	61069	0.00150	Zero	0.008
N	Timken	01-73	303796	0.00150	10	0.009
P	Timken	01-67	66180	0.00150	30	0.008
Q	Brenco	7-88	61094	0.00150	30	0.009
R	Brenco	7-88	61092	0.00150	30	0.011
S	Timken	01-87	1697	0.00150	30	0.008

Before the bearings were applied, the journal diameter of each axle was measured using a snap gage. Table 2 summarizes the pre-test axle journal measurements.

Table 2. RBFM Pre-Test Axle Journal Measurements

BEARING ID	OBWR (inches)	OBCS (inches)	IBCS (inches)	IBWR (inches)
C	6.1893	6.1890	6.1894	6.1895
D	6.1895	6.1890	6.1286	6.1897
E	6.1895	6.1892	6.1894	6.1898
F	6.1894	6.1894	6.1895	6.1898
G	6.1900	6.1898	6.1900	6.1903
H	6.1901	6.1898	6.1899	6.1902
I	6.1901	6.1898	6.1900	6.1903
J	6.1903	6.1902	6.1903	6.1903
K	6.1902	6.1902	6.1900	6.1904
L	6.1905	6.1904	6.1905	6.1905
M	6.1902	6.1902	6.1904	6.1905
N	6.1905	6.1901	6.1906	6.1905
P	6.1905	6.1905	6.1905	6.1905
Q	6.1905	6.1905	6.1905	6.1905
R	6.1908	6.1908	6.1907	6.1908
S	6.1905	6.1904	6.1903	6.1904

Note: OBWR - Outboard wear ring seat IBCS - Inboard cone seat
OBCS - Outboard cone seat IBWR - Inboard wear ring seat

3.1.1 Onboard Instrumentation

Two type K thermocouples were bonded to the bottom surface of each bearing adapter near the bearing cup raceways to monitor the operating temperature of each test bearing.

Hot bearing detector bolts, provided by RASTECH, were also installed in the end cap of each bearing to provide a visual indicator in the event of an over-temperature event.

3.1.2 Wayside Instrumentation

Three HBD systems were used in the RBFM test. The HTL was already equipped with a HBD system located in Section 02. A HBD/ABD system, provided by the Servo Corporation of America (Servo), was installed in Section 05 of the HTL along with a HBD system provided by Harmon Electronics Incorporated (Harmon). The rail mounted infrared transducers of the Servo HBD were aligned to intercept radiation coming from the inboard cup raceway. The rail mounted infrared transducers of the Harmon HBD were aligned to intercept radiation coming from the outboard cup raceway. This configuration allowed for simultaneous measurement of the operating temperature of a given roller bearing at the inboard and outboard cup raceways from the wayside. Figure 7 is a diagram showing the transducer alignment scheme employed, the HTL, and the location of the HBD systems.

The Servo HBD system converts the output of the rail mounted infrared transducers to an analog signal proportional to bearing operating temperature, relative to ambient temperature, expressed in degrees Fahrenheit above ambient (F°). The alarm threshold of all three HBD systems was set to 180 F°. All three systems were calibrated following the manufacturer's recommended guidelines prior to the start of the on-track test.

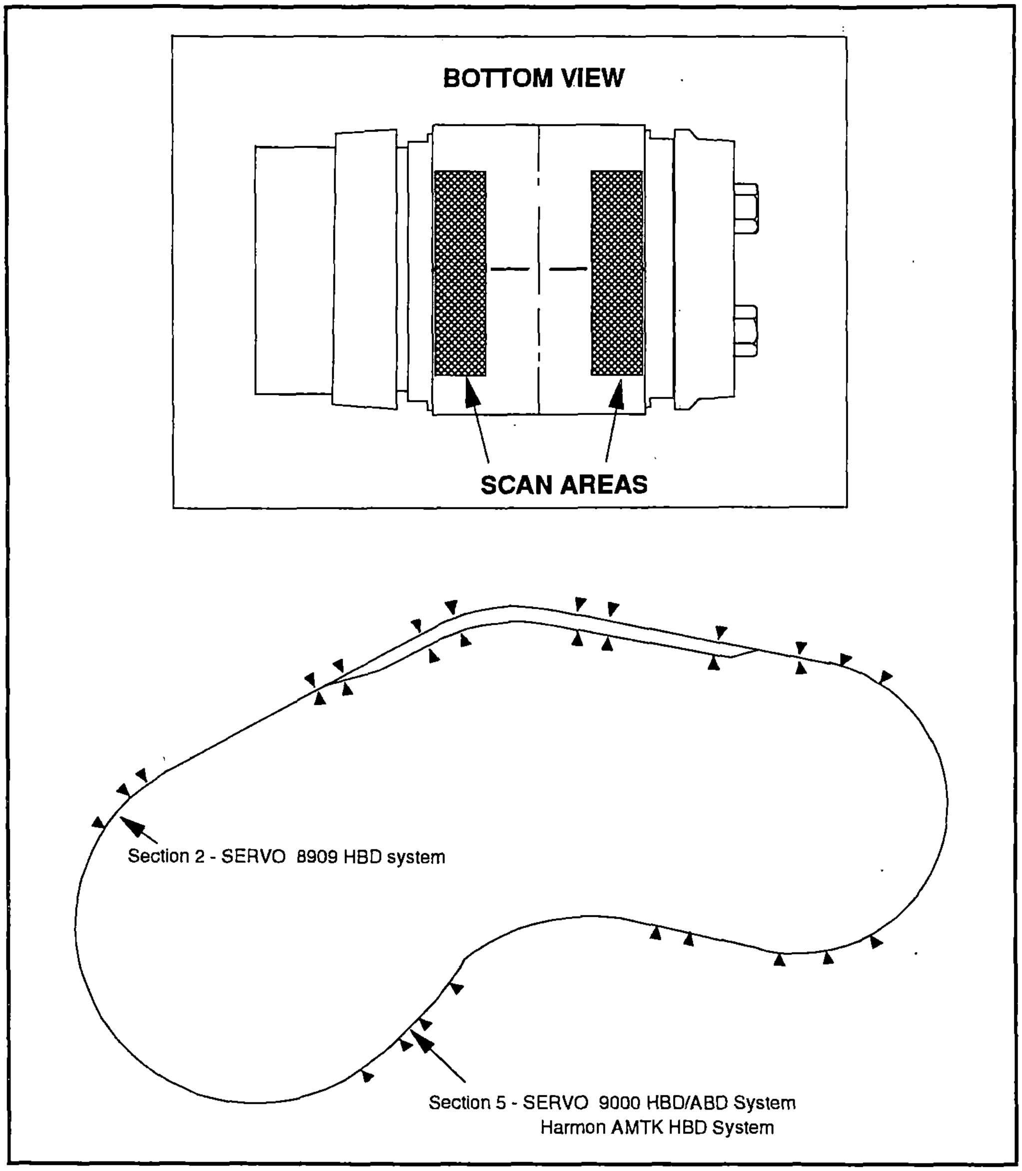

Figure 7. Wayside Detector Location on the HTL

The ABD system utilized in this test is a commercially available design that employs trackside microphones enclosed in weather proof boxes. The height of the microphones above the railhead was adjusted to be approximately the same height as the bearings. The Servo ABD system evaluates the output of the trackside microphones using filters, adjusted for train speed, set for specific frequencies associated with defects on the rolling contact surfaces of the bearing. The output of the filters is converted to an analog signal proportional to defect severity. The alarm threshold for the ABD was set following the manufacturer's recommended guidelines before the start of the on-track test.

3.1.3 Onboard Data Acquisition

A data logger, mounted to one of the test cars, was used to collect operating temperature data from each of the thermocouples on the test bearings.

3.2 RBFM MINI-TEST

Special train operations were conducted on June 10, 1993, to obtain acoustic and mechanical vibration data, and bearing operating temperature data from test bearings D and S. The instrumentation described in Section 3.2.1 was installed on the test bearings before operating the test cars and two locomotives at 10, 20, 25, 30, 35, 40, and 45 mph on the HTL . The data collected during the mini-test was provided to the University of Illinois for use in an AAR sponsored program to develop an improved wayside train inspection system that uses neural networks to evaluate acoustic data from various freight car and locomotive components.

3.2.1 Onboard Instrumentation

In addition to the instrumentation described in Section 3.1.1, an acceleration sensor, having a frequency response from DC to 15 kHz, and a high frequency microphone having a frequency response from DC to 25 kHZ, were installed on test bearings D and S. A Kyowa magnetic tape recorder having a frequency response from DC to 40 kHZ was used to record the data.

3.2.2 Wayside Instrumentation

The wayside instrumentation for the experiment was the same as described in Section 3.1.2.

3.2.3 Onboard Data Acquisition

The output signals of the acceleration sensors and microphones, and the thermocouples were recorded on FM tape over a frequency ranging from zero to 40 kHz.

3.3 CONE BORE GROWTH (CBG) TEST

This test is a continuation from work previously performed. Sixteen 125-ton capaciy, AP Class G, roller bearings with the axle journal/bearing cone interference fit and grease content combinations detailed in Table 3 were operated initially for 7,000 miles on the HTL under two fully loaded 125-ton capacity cars. The bearings were provided by Brenco.

Table 3. Initial CBG Test Bearing Summary

BEARING ID	DATE	SERIAL NUMBER	FIT (inches)	GREASE (ounces)	*LATERAL (inches)
1A	12-80	11614	0.0025	32	0.009
1B	09-81	11838	0.0025	24	0.010
2A	07-88	11845	0.0025	32	0.011
2B	07-88	11586	0.0025	24	0.018
3A	07-88	11587	0.0025	32	0.009
3B	07-88	11850	0.0025	24	0.011
4A	07-88	11843	0.0025	32	0.010
4B	07-88	11872	0.0025	24	0.006
5A	08-80	11588	0.0050	32	0.006
5B	07-88	11869	0.0050	24	0.008
6A	01-87	11865	0.0050	32	0.008
6B	01-87	11866	0.0050	24	0.008
7A	07-88	11628	0.0050	32	0.014
7B	01-73	11585	0.0050	24	0.009
8A	07-88	11599	0.0050	32	0.015
8B	09-73	11605	0.0050	24	0.011

* Mounted lateral

At the completion of the initial on-track tests, the bearings were removed from the axles, cleaned, inspected for damage, and returned to Brenco for post-test cone bore measurements.

Under the current research effort, the bearings were re-installed on the axles and returned to service for an additional 20,000 miles of operation. Table 4 lists the grease content and interference fit combinations tested.

Table 4. Current CBG Test Bearing Summary

BEARING ID	DATE	SERIAL NUMBER	FIT (inches)	GREASE (ounces)	*LATERAL (inches)
1A	12-80	11614	0.0025	44	0.009
1B	09-81	11838	0.0025	24	0.010
2A	07-88	11845	0.0025	44	0.011
2B	07-88	11586	0.0025	24	0.018
3A	07-88	11587	0.0025	44	0.009
3B	07-88	11850	0.0025	24	0.011
4A	07-88	11843	0.0025	44	0.010
4B	07-88	11872	0.0025	24	0.006
5A	08-80	11588	0.0050	44	0.006
5B	07-88	11869	0.0050	24	0.008
6A	01-87	11865	0.0050	44	0.008
6B	01-87	11866	0.0050	24	0.008
7A	06-91	28971	0.0050	44	0.014
7B	01-73	11585	0.0050	24	0.009
8A	07-88	11599	0.0050	44	0.015
8B	09-73	11605	0.0050	24	0.011

*** Mounted lateral**

Before continuing the test, the journals of the test axles were measured at the outboard and inboard cone seats (OBCS and IBCS) by AAR personnel. Table 5 lists the axle journal measurements.

Table 5. CBG Pre-Test Axle Journal Measurement Summary

BEARING ID	OBCS (inches)	IBCS (inches)
1A	7.0038	7.0041
1B	7.0035	7.0036
2A	7.0036	7.0040
2B	7.0038	7.0041
3A	7.0036	7.0037
3B	7.0033	7.0036
4A	7.0034	7.0037
4B	7.0037	7.0038
5A	7.0028	7.0028
5B	7.0028	7.0028
6A	7.0028	7.0029
6B	7.0028	7.0028
7A	7.0029	7.0032
7B	7.0028	7.0028
8A	7.0026	7.0028
8B	7.0028	7.0028

Note: OBCS - Outboard cone seat IBCS - Inboard cone seat

The wheel sets equipped with the CBG test bearings were installed under two loaded 125-ton capacity open top hopper cars. The cars were operated as part of the HAL train on the HTL.

At the completion of this phase of testing, the bearings were removed again from the axles, disassembled, and cleaned. The bearings were inspected for defects and returned to Brenco for post test measurement of the cone bore diameters. The axle journals were measured by AAR personnel.

3.3.1 Onboard Instrumentation

Each bearing was equipped with two type K thermocouples. The thermocouples were bonded to the bottom of the bearing adapter over the bearing cup.

RASTECH hot bearing detector bolts were installed in the end cap of each bearing to provide a visual indicator in the event of an over-temperature event.

3.3.2 Wayside Instrumentation

The wayside instrumentation for the experiment was the same as described in Section 3.1.2.

3.3.3 Onboard Data Acquisition

A data logger, mounted to one of the CBG test cars, was used to collect operating temperature data from each of the thermocouples on the test bearings.

3.4 RACEWAY DEFECT GROWTH RATE (RDGR) TEST

Three 100-ton capacity, AP Class F, bearings were evaluated in the RDGR test. Before starting the on-track test, the roller bearings were removed from the axles, disassembled, and cleaned. The number, type, and size of raceway defects were documented for each test bearing. After inspection, the bearings were reassembled and mounted on the axles. Each wheel set with a RDGR test bearing was installed in the leading axle position of the B-end of a fully loaded 100-ton capacity car (three cars total). The RDGR test cars were operated as part of the HAL train on the HTL. Pre-test bearing inspection data is provided in Table 6.

Table 6. RDGR Pre-Test Bearing Data Summary

DEFECT TYPE	DEFECT LOCATION	NUMBER OF DEFECTS	DEFECT SIZE (SQ-IN)	END PLAY (inches)	BOLT TORQUE (ft-lb)
Brinell	Cup Race	1	0.28	0.005	375
Spall	Cup Race	1	0.11	0.003	375
Spall	Cone Race	1	0.76	0.002	375

At the completion of on-track testing, the bearings were removed from the axles, disassembled, and cleaned. The number, type, and size of raceway defects were documented for each test bearing.

3.4.1 Onboard Instrumentation

RASTECH hot bearing detector bolts were installed in the end cap of each bearing to provide a visual indicator in the event of an over-temperature event.

3.4.2 Wayside Instrumentation

The wayside instrumentation for the experiment was the same as described in Section 3.1.2.

4.0 TEST RESULTS

The results obtained in each of the tests are presented in the following subsections.

4.1 RBFM TEST

4.1.1 Unexpected Bearing Failures

In December 1992, while turning the HAL train end-for-end, the brakes on both RBFM test cars locked up due to cold weather conditions, which caused extensive thermal damage to the wheels. In order to continue the RBFM test, the damaged wheels were removed and replaced by AAR. The test cars were re-introduced into the HAL train on January 5, 1993.

On March 17, test bearing J experienced thermal runaway. This particular bearing had completed 17,320 miles of operation in previous testing, and an additional 10,557 miles of operation in the current test, resulting in a total of 27,877 miles of operation prior to failure.

An inspection of bearing J was conducted on April 5, 1993, to determine the causes of the failure. The inspection revealed that the bearing had failed due to misapplication of the bearing adapter on the bearing cup.

Prior to the start of the on-track tests, mechanical stops were welded onto the bearing cups to limit damage to the thermocouples used to measure bearing operating temperature caused by cup motion relative to the bearing adapter. The mechanical stops on bearing J, and the bearing on the other end of the axle, bearing N, had been inadvertently positioned under the bearing adapter when the wheel sets were installed in December 1992. This resulted in a point loading condition that caused the cups of both bearings to fracture. The size of the fractured cup section on bearing J was small enough to fit between the rollers and the cage assembly, causing the bearing to seize. The size of the fractured cup section on bearing N was much larger, and could not fit between the rollers and the cage assembly. As a result, this bearing did not fail catastrophically.

The other bearings on the test cars were also inspected to ensure that a similar condition did not exist on any of the other wheel sets. The inspection revealed that bearings I, and K also had fractured cups caused by the same condition. The wheel sets equipped with these test bearings were removed and replaced to ensure the safety of the HAL train. Table 7 provides a summary of the bearings that were removed from service on April 5, and lists the mileage that the bearings had completed at the time of removal.

Table 7. RBFM Test Bearings Removed from Service April 5, 1993

BEARING ID	MILEAGE CURRENT TEST	TOTAL MILEAGE
I	10,557	27,877
J	10,557	27,877
K	10,557	27,877
N	10,557	27,877

4.1.2 Acoustic and Thermal Behavior of Bearing D

At the beginning of the current on-track test, the acoustic and thermal behavior of bearing D was similar to all of the other test bearings. There were no external indications that this bearing had developed a grooved axle condition. Figure 8 shows the thermal behavior of bearing D as compared to bearing S, a defect free bearing, after 5,645 miles of operation on the HTL in the current test.

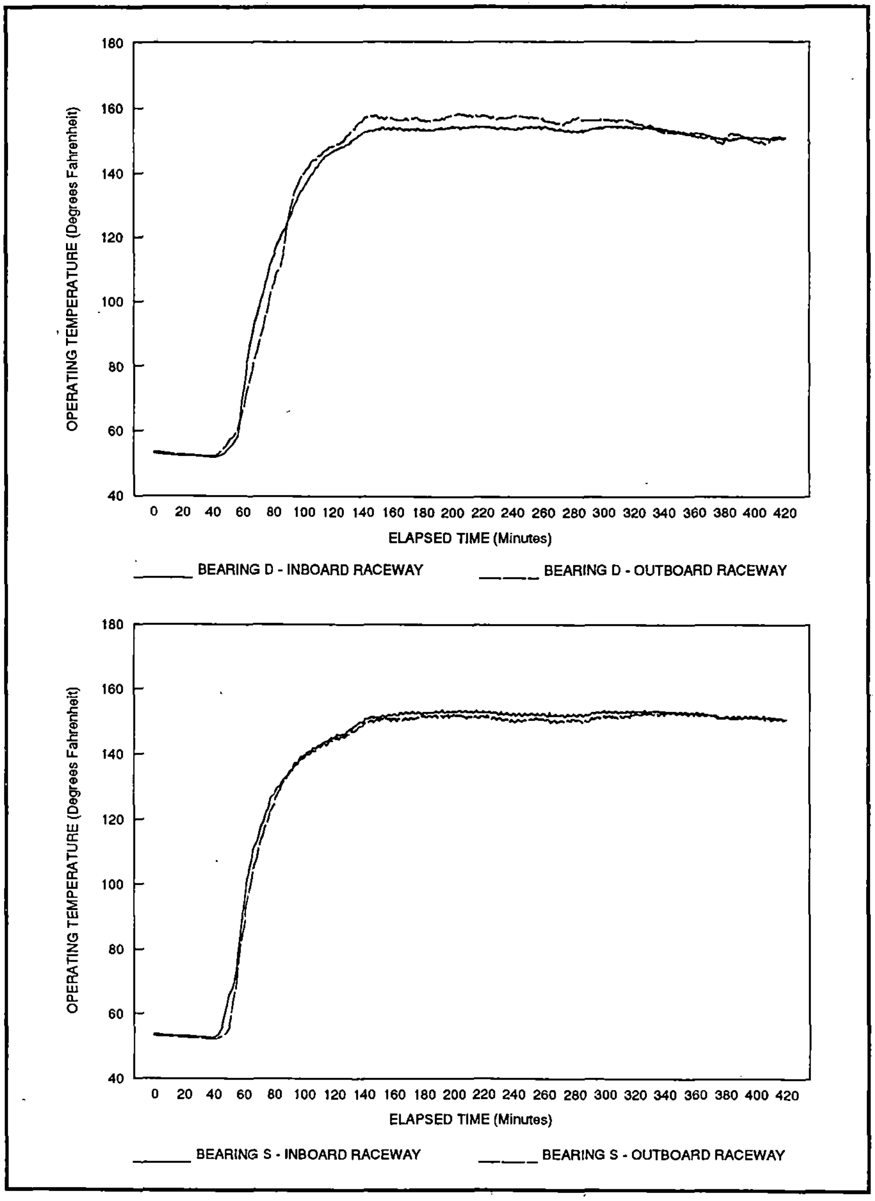

Figure 8. Thermal Behavior - Bearing D and S

Inspection of Figure 8 shows that the thermal behavior is very similar for both bearings even though bearing D has a grooved axle condition and bearing S is a bearing with no defects. Similar results were obtained using the inboard/outboard wayside HBD system. Inboard/outboard wayside HBD data collected for 10 consecutive laps of the HTL are shown in Table 8.

Table 8. Initial HBD Data for Bearing D and S

HTL LAP COUNT	INBOARD SCANNER (°F)		OUTBOARD SCANNER (°F)	
	D	S	D	S
20	138	136	140	135
21	141	139	142	137
23	142	140	146	139
24	145	140	148	144
25	140	144	145	141
26	145	143	147	138
27	143	147	144	145
28	144	143	147	144
29	145	140	145	143
30	149	144	147	144

A comparison of the wayside HBD temperature data at the onboard temperature data for bearings D and S shows that the wayside HBD temperature data is approximately 10 F° lower than the onboard temperature data. It should be noted that the wayside HBD rail mounted thermal transducers were aligned to intercept infrared radiation from the side of the bearing cup over each raceway, while the onboard temperature data was measured under the bearing adapter at the top of the bearing cup over each raceway. Similar differences in temperature between the top of cup and the side of cup locations were measured in the previous test.

As the bearings accumulated additional mileage, the thermal behavior of bearing D began to change, as compared to the other test bearings. Figure 9 shows the thermal behavior of bearing D as compared to bearing S after 10,035 miles of operation on the HTL in the current test.

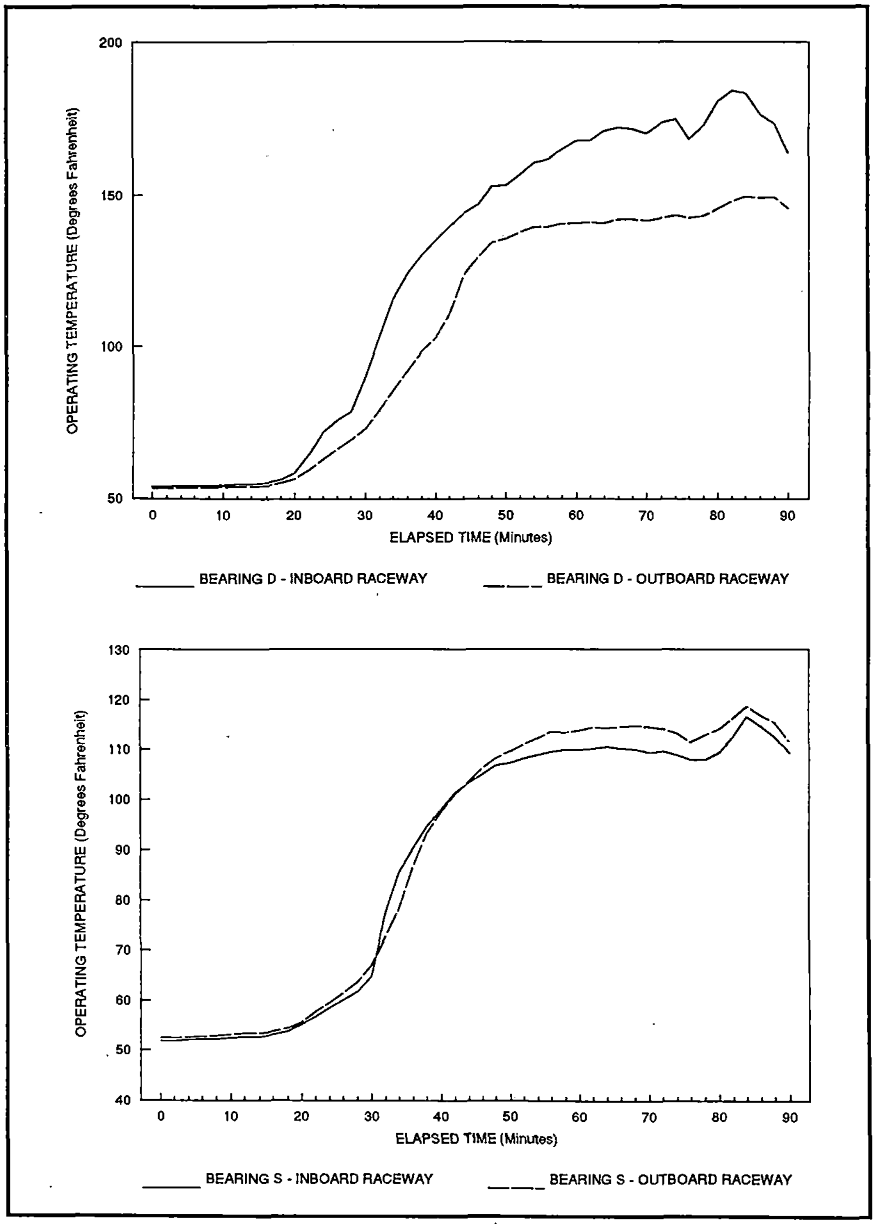

Figure 9. Thermal Behavior - Bearing D and S After 10,035 Miles of Operation

Inspection of Figure 9 shows that bearing D has developed a temperature gradient between the inboard and outboard raceways. Once again, similar results were obtained using the inboard/outboard wayside HBD system. Inboard/outboard wayside HBD data for 10 consecutive laps of the HTL are shown in Table 9.

Table 9. HBD Data for Bearing D and S after 10,035 Miles of Operation

HTL LAP COUNT	INBOARD SCANNER (°F)		OUTBOARD SCANNER (°F)	
	D	S	D	S
10	139	97	122	98
11	145	99	128	102
12	153	101	132	104
13	157	102	133	105
14	160	102	133	106
15	164	102	134	107
16	162	101	134	107
17	167	101	135	105
18	165	100	135	105
19	170	105	140	108

The data in Table 9 demonstrates that the thermal gradient across the bearing cup can be measured from the wayside using commercially available HBD equipment.

The temperature gradient was observed to increase with additional mileage. Figure 10 shows the thermal bearing D as compared to bearing S after 12,775 miles of operation in the current test.

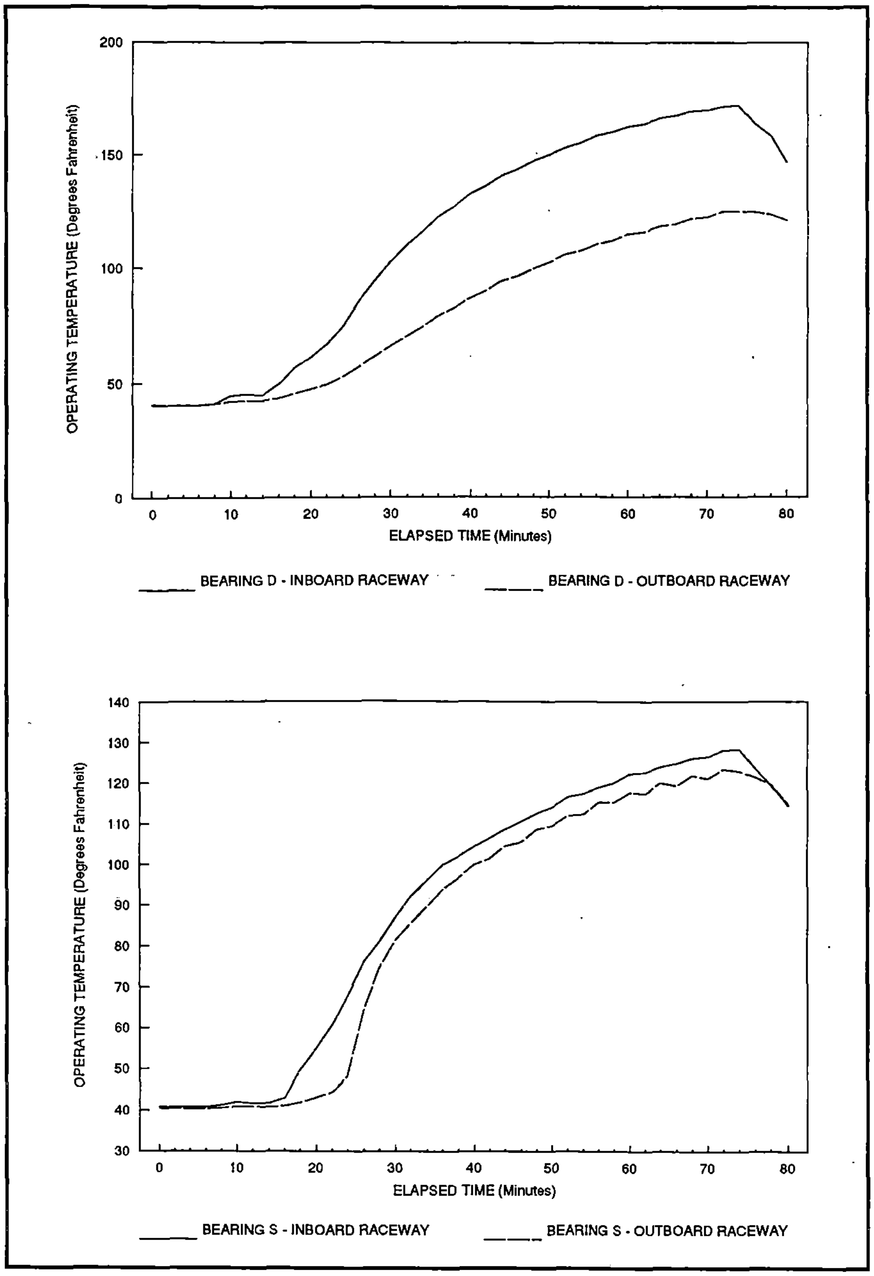

Figure 10. Thermal Behavior - Bearing D and S After 12,775 Miles of Operation

The data shows that the temperature gradient between the inboard and outboard raceways on bearing D reached nearly 50 F°.

The corresponding wayside inboard/outboard data for bearings D and S collected for 10 consecutive laps of the HTL are shown in Table 10.

Table 10. HBD Data for Bearing D and S after 12,775 Miles of Operation

HTL LAP COUNT	INBOARD SCANNER (°F)		OUTBOARD SCANNER (°F)	
	D	S	D	S
10	126	97	80	92
11	134	101	87	98
12	140	104	93	99
13	146	107	98	102
14	150	110	102	105
15	154	113	106	107
16	157	115	110	108
17	160	116	113	109
18	162	115	115	111
19	165	118	115	113

Unusual acoustic emissions from bearing D were noted on April 7, while inspecting the car during normal operation at 40 mph on the HTL. It should be noted that the acoustic emissions generated by bearing D did not initiate an alarm from the wayside ABD system.

At this point in the test, the wheel set equipped with bearing D and F was removed from service so that additional testing at a later date. Bearings D and F, installed on this wheel set, had completed 17,320 miles of operation during previous testing and an additional 12,775 miles of operation in the current test, resulting in a total of 30,095 miles of operation.

The wheel set equipped with bearings D and F was re-installed under the test car on May 4. The instrumentation listed in Section 3.2.2 was installed on bearings D and S on May 5. A special train, consisting of two locomotives and the two RBFM test cars, was operated on the HTL on June 10, to document the acoustic emissions and vibration signatures of bearings D and S.

On June 15, the wheel set equipped with bearing D and F was removed from the test car. The RBFM test cars were operated on the HTL as part of a special HAL train during the period from July to October 1993. The cars completed an additional 5,340 miles of operation in this train. The remaining RBFM test bearings completed 20,000 miles of operation in this test, in addition to the 17,320 mileage accumulated during previous testing, resulting in a total of 37,320 miles of operation.

4.1.3 Bearing Inspection Results

All of the test bearings were removed from the axles and inspected. The results of the inspection for each of the test bearings is provided below.

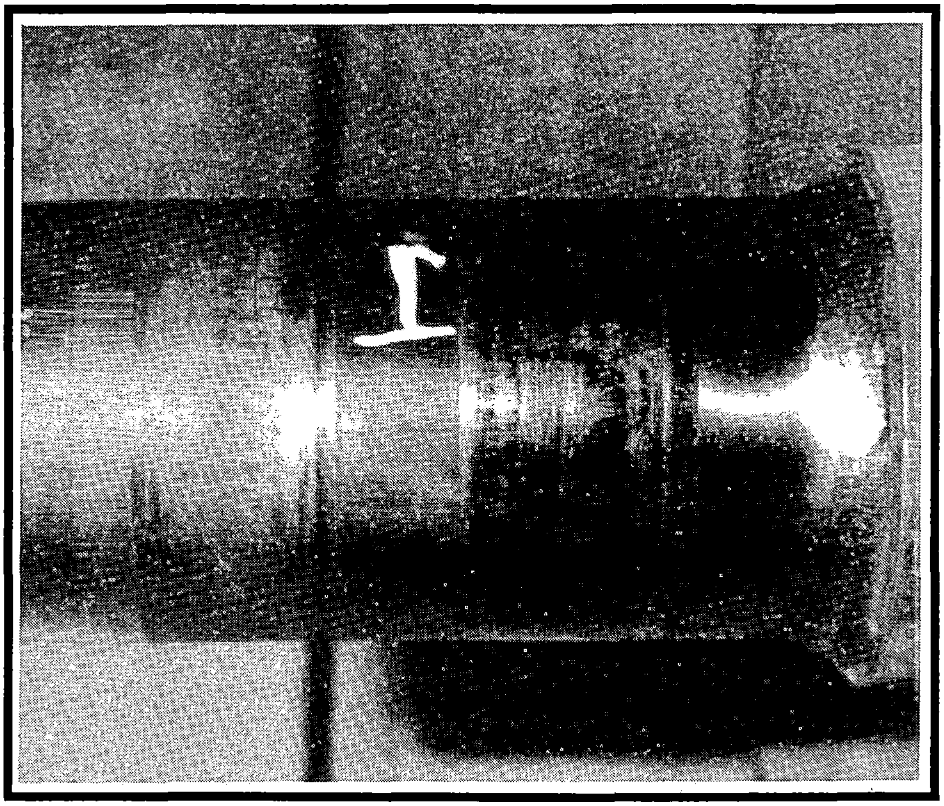

Figure 11. RBFM Post Test Axle Journal Condition -- Bearing C

Bearing C

Post test inspection of bearing C showed that the inboard cone bore diameter remained unchanged at 6.1898 inches, while the outboard cone bore diameter increased from 6.1895 inches to 6.1897 inches due to rotation of the cones on the axle journal. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard cone seat remained unchanged at 6.1894 inches, while the diameter at the outboard cone seat decreased from 6.1893 inches to 6.1890 inches. Figure 11 shows the condition of the axle journal at the completion of the test.

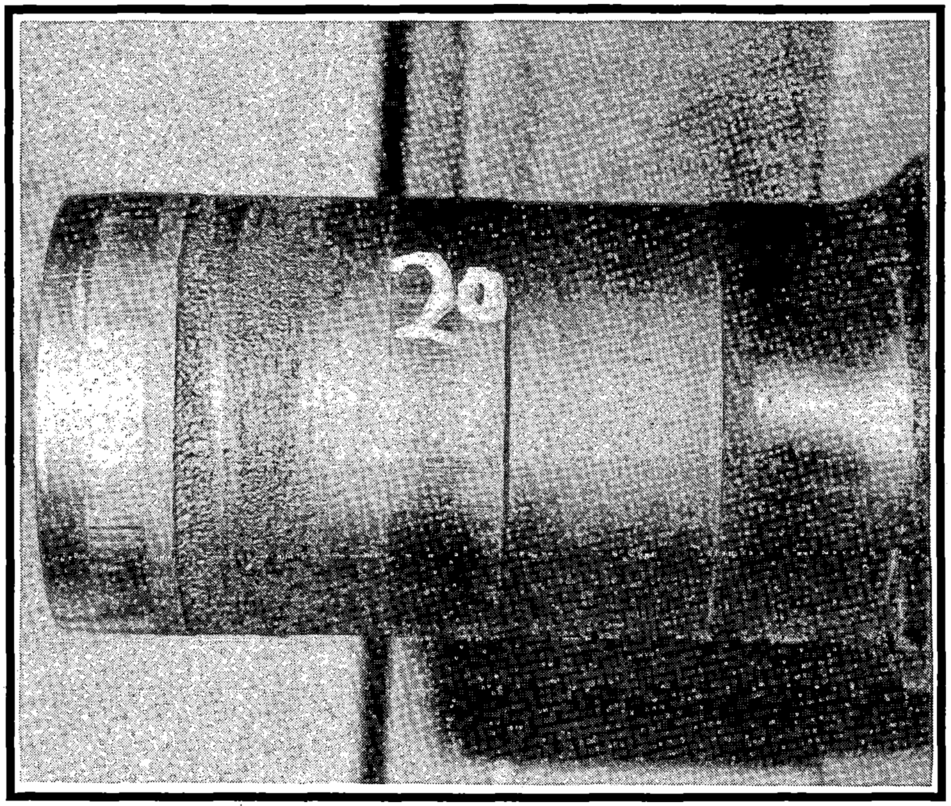

Figure 12. RBFM Post Test Axle Journal Condition -- Bearing D

Bearing D

Post test inspection of bearing D showed that the inboard cone bore diameter increased from 6.2019 inches to 6.2150 inches, while the outboard cone bore diameter increased from 6.1896 inches to 6.1951 inches due to rotation of the cones on the axle journal. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for this bearing are discussed in detail in Section 4.1.2.

The axle journal diameter at the inboard cone seat decreased from 6.1286 inches to 6.1000 inches during the test, while the diameter at the outboard cone seat decreased from 6.1890 inches to 6.1600 inches. Figure 12 shows the condition of the axle journal at the completion of the test.

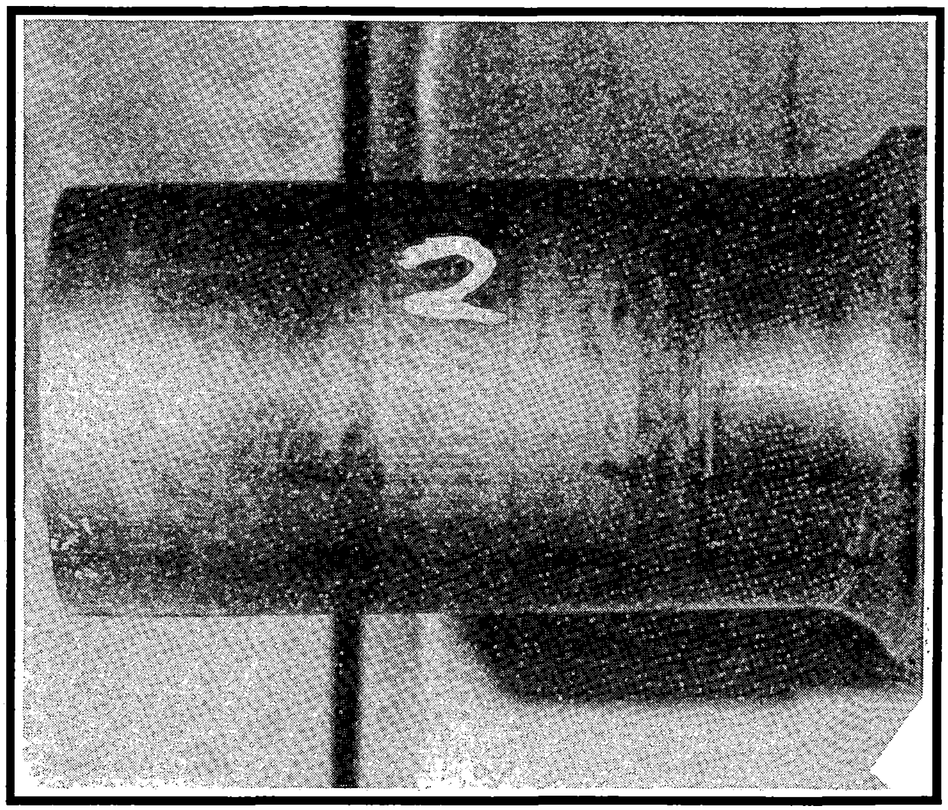

Figure 13. RBFM Post Test Axle Journal Condition -- Bearing E

Bearing E

Post test inspection of bearing E showed that the inboard and outboard cone bore diameters remained unchanged at 6.1899 inches, and 6.1897 inches respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1894 inches and 6.1892 inches, respectively. Figure 13 shows the condition of the axle journal at the completion of the test.

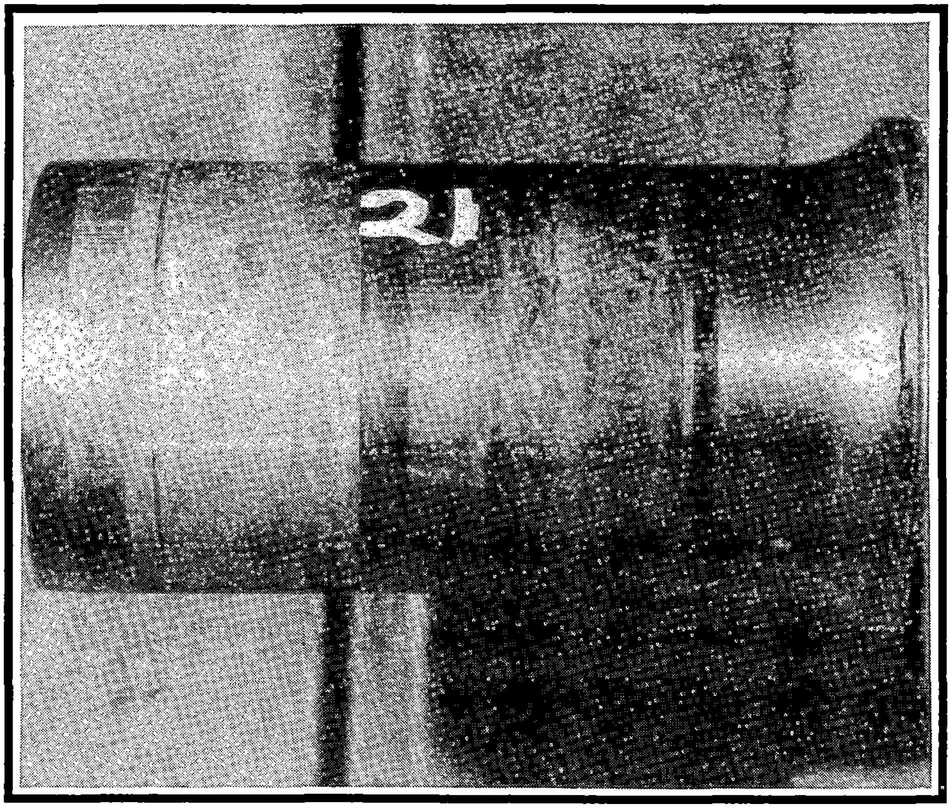

Figure 14. RBFM Post Test Axle Journal Condition -- Bearing F

Bearing F

Post test inspection of bearing F showed that the inboard cone bore diameter increased from 6.1900 inches to 6.1902 inches due to rotation of the cone on the axle journal, while the outboard cone bore diameter remained unchanged at 6.1894 inches. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard cone seat decreased from 6.1895 inches to 6.1893 inches during the test, while the diameter at the outboard cone seat remained unchanged at 6.1894 inches. Figure 14 shows the condition of the axle journal at the completion of the test.

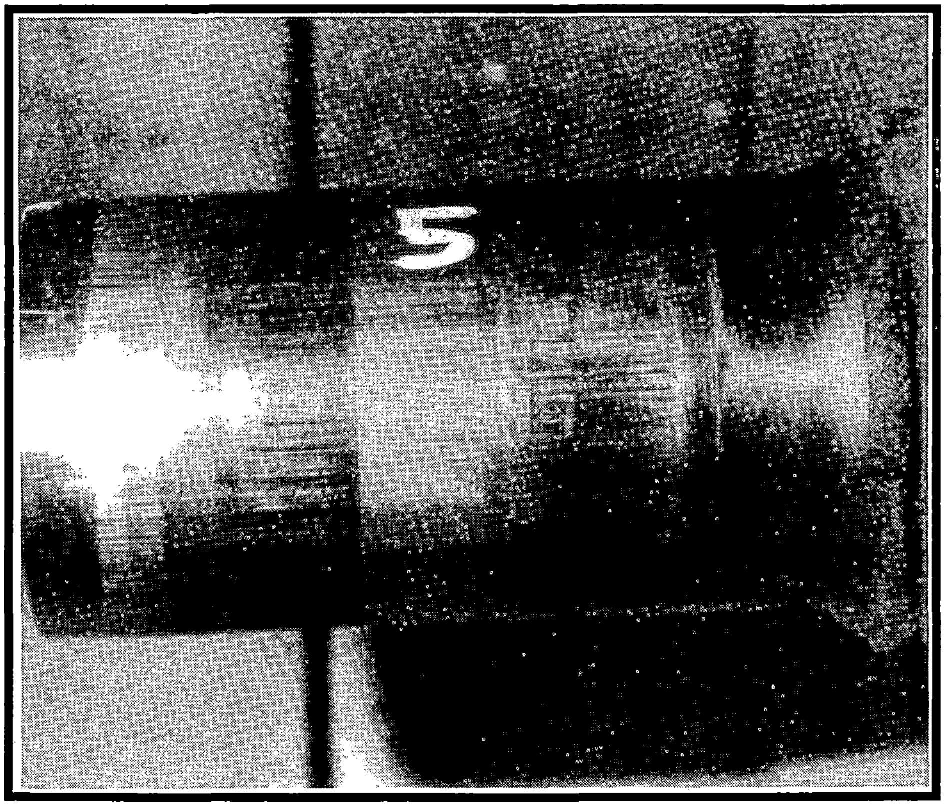

Figure 15. RBFM Post Test Axle Journal Condition -- Bearing G

Bearing G

Post test inspection of bearing G showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1893 inches and at 6.1894 inches, respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1900 inches and 6.1901 inches, respectively. Figure 15 shows the condition of the axle journal at the completion of the test.

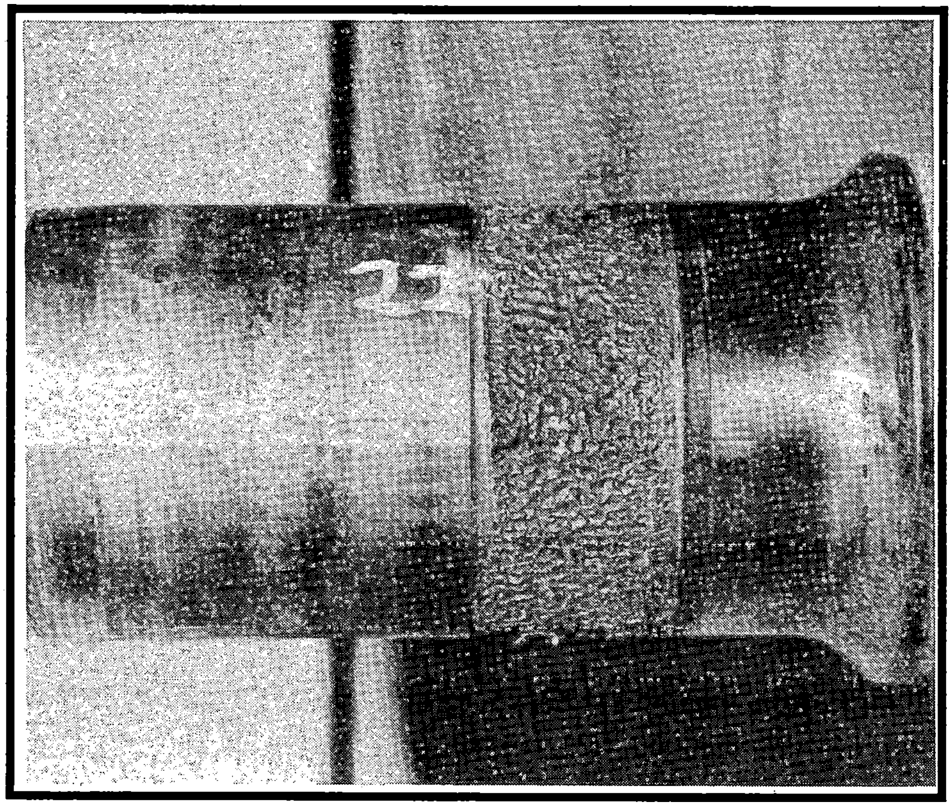

Figure 16. RBFM Post Test Axle Journal Condition -- Bearing H

Bearing H

Post test inspection of bearing H showed that the inboard cone bore diameter increased from 6.1896 inches to 6.1902 inches, while the outboard cone bore diameter increased from 6.1895 inches to 6.1900 inches due to rotation of the cones on the axle journal. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard cone seat decreased from 6.1899 inches to 6.1224 inches during the test, while the diameter at the outboard cone seat decreased from 6.1898 inches to 6.1890 inches. Figure 16 shows the condition of the axle journal at the completion of the test.

Bearing I

Post test inspection of bearing I showed that the bore diameter of the inboard and outboard cones seats remained unchanged at 6.18925 inches and 6.18905 inches, respectively. This bearing experienced a cup raceway fracture caused by a mis-application of the bearing adapter relative to mechanical stops welded to the bearing cup. The stops were applied to limit cup motion to the bearing adapter, as discussed in Section 4.1.1. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1900 inches and 6.1898 inches, respectively.

Bearing J

Bearing J failed catastrophically as discussed in Section 4.1.1 of this report. No useful dimensional data was available for the bearing cones or the axle journal due to excessive damage incurred during failure.

Bearing K

Post test inspection of bearing K showed that bore diameter of the inboard and outboard cones remained unchanged at 6.18925 inches and 6.18945 inches, respectively. This bearing experienced a cup raceway fracture caused by a mis-application of the bearing adapter relative to mechanical stops welded to the bearing cup. The stops were applied to limit cup motion relative to the bearing adapter, as discussed in Section 4.1.1. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1900 inches and 6.1902 inches, respectively.

Bearing L

Post test inspection of bearing L showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1890 inches and 6.1889 inches, respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1905 inches and 6.1904 inches, respectively.

Bearing M

Post test inspection of bearing M showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1889 inches and 6.1887 inches, respectively. This bearing experienced a cup raceway fracture caused by a misapplication of the bearing adapter relative to mechanical stops welded to the bearing cup to limit cup motion relative to the bearing adapter as discussed in Section 4.1.1. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1904 inches and 6.1902 inches, respectively.

Bearing N

Post test inspection of bearing N showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1891 inches and 6.1886 inches, respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1906 inches and 6.1901 inches, respectively.

Bearing P

Post test inspection of bearing P showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1890 inches. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1905 inches.

Bearing Q

Post test inspection of bearing Q showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1890 inches. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1905 inches.

Bearing R

Post test inspection of bearing R showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1892 inches and 6.1893 inches, respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1907 inches and 6.1908 inches, respectively.

Bearing S

Post test inspection of bearing S showed that the bore diameter of the inboard and outboard cones remained unchanged at 6.1888 inches and 6.1889 inches, respectively. No defects developed on any of the other bearing components during the test. The thermal and acoustic data for the bearing never indicated a defective condition during the test.

The axle journal diameter at the inboard and outboard cone seats remained unchanged at 6.1903 inches and 6.1904 inches, respectively.

A summary of the journal measurements for all of the axles is provided in Table 11.

Table 11. RBFM Post Test Axle Journal Measurements

BEARING	OBWR	OBCS	IBCS	IBWR
C	6.1891	6.1890	6.1894	6.1897
D	6.1896	6.1600	6.1000	6.1895
E	6.1894	6.1892	6.1894	6.1895
F	6.1895	6.1894	6.1893	6.1896
G	6.1898	6.1901	6.1900	6.1901
H	6.1900	6.1890	6.1224	6.1900
I	6.1901	6.1898	6.1900	6.1903
J	NA	NA	NA	NA
K	6.1902	6.1902	6.1900	6.1904
L	6.1905	6.1904	6.1905	6.1905
M	6.1902	6.1902	6.1904	6.1905
N	6.1905	6.1901	6.1906	6.1905
P	6.1905	6.1905	6.1905	6.1905
Q	6.1905	6.1905	6.1905	6.1905
R	6.1908	6.1908	6.1907	6.1908
S	6.1905	6.1904	6.1903	6.1904

Note: OBWR - Outboard wear ring seat
OBCS - Outboard cone seat
IBCS - Inboard cone seat
IBWR - Inboard wear ring seat

4.2 CONE BORE GROWTH/RUN-IN TEMPERATURE TEST

The CBG test bearings were operated for an additional 20,000 miles on the HTL during the current test. Temperature data from each of the bearings was monitored on a daily basis. The bearings with a 0.0050-inch interference fit, charged with 44 ounces of grease, had the highest operating temperature, approximately 180 °F; the operating temperature of the bearings with a 0.0025-inch interference fit, charged with 24 ounces of grease, was approximately 30 F° lower.

At the completion of the current on-track tests, the bearings and axles were inspected. Table 12 lists the axle journal measurements obtained during the inspection.

Table 12. CBG Post Test Journal Measurement Summary

BEARING ID	OBCS (inches)	IBCS (inches)
1A	7.0038	7.0041
1B	7.0035	7.0036
2A	7.0036	7.0040
2B	7.0038	7.0041
3A	7.0036	7.0037
3B	7.0033	7.0036
4A	7.0034	7.0037
4B	7.0037	7.0038
6A	7.0028	7.0029
6B	7.0028	7.0028
7A	7.0029	7.0032
7B	7.0028	7.0028
5A	7.0028	7.0028
5B	7.0028	7.0028
8A	7.0026	7.0028
8B	7.0028	7.0028

Note: OBCS - Outboard cone seat IBCS - Inboard cone seat

Table 13 summarizes the post test CBG bearing inspection results.

Table 13. Post Test CBG Test Bearing Inspection Results Summary

BEARING ID	END CAP BOLT TORQUE (ft-lb)	GREASE (ounces)	*LATERAL (inches)
1A	All Bolts Within AAR Spec+	41	0.011
1B	All Bolts Within AAR Spec+	22	0.012
2A	All Bolts Within AAR Spec+	41	0.011
2B	All Bolts Within AAR Spec+	22	0.018
3A	All Bolts Within AAR Spec+	42	0.010
3B	All Bolts Within AAR Spec+	20	0.012
4A	All Bolts Within AAR Spec+	42	0.011
4B	All Bolts Within AAR Spec+	21	0.008
5A	All Bolts Within AAR Spec+	43	0.005
5B	All Bolts Within AAR Spec+	21	0.008
6A	All Bolts Within AAR Spec+	42	0.009
6B	All Bolts Within AAR Spec+	23	0.008
7A	All Bolts Within AAR Spec+	42	0.014
7B	All Bolts Within AAR Spec+	23	0.011
8A	All Bolts Within AAR Spec+	41	0.015
8B	All Bolts Within AAR Spec+	22	0.011

*** Mounted lateral** **+ 390 ft-lb to 420 ft-lb**

The bearings were returned to Brenco where the cones were measured to determine bore growth. A summary of the cone bore growth that occurred during previous testing and during the current test is provided in Table 14.

Table 14. Post Test Cone Bore Growth Data Summary

BEARING ID	OBC GROWTH (inches) PREVIOUS TEST	OBC GROWTH (inches) CURRENT TEST	TOTAL OBC GROWTH (inches)	IBC GROWTH (inches) PREVIOUS TEST	IBC GROWTH (inches) CURRENT TEST	TOTAL IBC GROWTH (inches)
1A	0.00010	0.00015	0.00025	0.00015	0.00010	0.00025
1B	0.00050	0.00015	0.00065	0.00005	0.00015	0.00020
2A	0.00030	0.00030	0.00060	0.00020	0.00025	0.00045
2B	0.00035	0.00015	0.00050	0.00015	0.00015	0.00030
3A	0.00040	0.00020	0.00060	0.00030	0.00025	0.00055
3B	0.00010	0.00015	0.00025	0.00010*	0.00050	NA
4A	0.00040	0.00020	0.00060	0.00040	0.00025	0.00065
4B	0.00010	0.00005	0.00015	0.00015	0.00015	0.00030
5A	0.00050	0.00025	0.00075	0.00050	0.00020	0.00070
5B	0.00085*	0.00050	NA	0.00080*	0.00060	NA
6A	0.00030	0.00010	0.00040	0.00065*	0.00075	NA
6B	0.00060*	0.00065	NA	0.00080*	0.00035	NA
7A	0.00040	0.00075	0.00115	0.00040	0.00020	0.00060
7B	0.00025	0.00005	0.00030	0.00050	0.00000	0.00050
8A	0.00055	0.00030	0.00085	0.00035	0.00015	0.00050
8B	0.00075*	0.00040	NA	0.00055	0.00050	0.00060

Note: OBC - Outboard cone IBC - Inboard cone *Cone replaced

The cone bore growth data in Table 14 indicates that initially the bearings with a 0.0050-inch interference fit, bearings 5A through 8B, experienced more bore growth than the bearings with a 0.0025-inch interference fit, bearings 1A through 4B. However, with additional mileage, the rate of bore growth slowed significantly for the bearings with a 0.0050-inch interference fit. As a result, the interference fit for these bearings remained near the maximum allowed by current AAR specifications.

4.3 ROLLER BEARING DEFECT GROWTH RATE TEST

The bearings completed 20,000 miles of operation during the current test. The bearings were inspected at the completion of the on-track tests to document the number and size of the raceway defects. A summary of the inspection results for each defect type is provided in the following subsections.

4.3.1 Cup Raceway Brinelling

The Brinelling defect in the bearing cup raceway did not increase in severity nor did any new Brinelling develop during the test. At the completion of the on-track testing, the bearing end play measured 0.005 inch and the end cap bolt torque values were within current AAR specifications (360 to 390 ft-lb) for a Class F bearing.

The bearing with the cup raceway Brinelling defect used in this test completed 19,000 miles of operation on the HTL in previous testing, bringing the total operating mileage to 39,000 with no progression in defect severity or number.

The wayside ABD system was able to consistently (lap after lap) identify this bearing as defective during the entire test period.

4.3.2 Cup Raceway Spall

The spall in the cup raceway increased from 0.11 sq-in to 0.28 sq-in. No additional spalls developed during the test. At the completion of the on-track testing, the bearing end play measured 0.0050 inch and the end cap bolt torque values were within current AAR specifications (360 to 390 ft-lb) for a Class F bearing.

The bearing used in the cup raceway spall progression test completed 19,000 miles of operation on the HTL in previous testing. In this earlier test, the spall defect increased a total of 0.5 sq-in during the test. The total operating mileage for this bearing is 39,000 and the total increase in defect size is 0.22 sq-in.

Initially, the wayside ABD system consistently (lap after lap) identified this bearing as defective. However after about 12,500 miles of operation in the current test, the amplitude of the signal produced by this defect no longer exceeded the alarm threshold of the ABD system.

4.3.3 Cone Raceway Spall

The spall in the cone raceway did not increase from its initial size of 0.76 sq-in, nor did any additional spalls develop during the test. At the completion of the on-track testing, the bearing end play measured 0.0050 inch, and the end cap bolt torque values were within the current AAR specifications (360 to 390 ft-lb) for a Class F bearing.

This bearing was operated initially for 19,000 miles on the HTL in previous testing. The defect did not increase in severity during the earlier test.

The wayside ABD system did not consistently (lap after lap) identify this bearing as defective, even though the defect made audible noise throughout the test. One possible reason for this, offered by the ABD system manufacturer, is that the ABD system, as currently designed, does not provide coverage for a complete wheel revolution for wheel sets equipped with 36-inch diameter wheels, and detection of a defect located on the cone raceway requires at least one complete revolution of the wheel.

5.0 CONCLUSIONS

The following subsections provide a summary of the conclusions for each test.

5.1 RBFM TEST

- Bearings on grooved axle journals developed measurable temperature gradients across the cup surface which can be used by wayside HBD systems designed to scan both the inboard and outboard bearing raceways to identify wheel sets with this defect type.
- A grooved axle condition developed under the outboard cone in bearing D during the test. No other defects developed on any of the roller bearing components.
- The operating temperature of bearing D never exceeded the alarm threshold of the wayside HBD systems.
- A thermal gradient developed across the cup surface of bearing D, which was measurable from the wayside using an HBD system designed to intercept radiation from both the inboard and outboard bearing cup raceways.
- Bearing D generated audible acoustic emissions during the test, although the acoustic emissions never caused any ABD system alarms.
- A grooved axle condition developed under the inboard cone in bearing H during the test. No defects developed on any of the roller bearing components.
- The operating temperature of bearing H never exceeded the alarm threshold of the wayside HBD systems.
- Bearing H did not generate any audible acoustic emissions during the test.
- None of the other axles or bearings developed any defects during the test.
- No mechanical failures occurred on the hot bearing detector bolts provided by RASTECH.

5.2 CONE BORE GROWTH TEST

- The bearings with a 0.0050-inch interference fit and charged with 44 ounces of grease exhibited the highest operating temperatures during the test.
- The bearings with a 0.0025-inch interference fit and charged with 24 ounces of grease exhibited the lowest operating temperatures during the test.
- The 0.0025- and 0.005-inch interference fit bearings charged with 24 ounces of grease exhibited lower operating temperatures than similar bearings charged with 44 ounces of grease. The effect of grease content on operating temperature was more pronounced for the bearings with a 0.0050-inch interference fit.
- The rate of bore growth for bearings with a 0.0050-inch interference fit slowed significantly with additional mileage.
- The interference fit of bearings with an initial interference fit of 0.0050 inch remained near the maximum allowed by current AAR specifications of 0.0045 inch.

5.3 RACEWAY DEFECT GROWTH TEST

- No measurable growth occurred for the cup raceway Brinell defect during the test.
- The ABD system was able to reliably identify the bearing with the cup raceway Brinell as a defective bearing.
- Measurable growth occurred for the cup spall defect during the test.
- Initially, the ABD system was able to reliably identify the bearing with the cup raceway spall as a defective bearing. However, after about 12,550 miles of operation in the current test, the amplitude of the acoustic signal generated by the bearing did not exceed the alarm threshold of the ABD system.
- No measurable growth occurred for the cone raceway spall defect during the test.

- The ABD system did not reliably identify the bearing with the cone raceway spall as a defective bearing. One possible reason for this, offered by the ABD manufacturer, is that the ABD, as currently designed, does not provide coverage for a complete wheel revolution for wheel sets equipped with 36-inch diameter wheels, and at least one complete wheel revolution is required to detect a defect located on the cone raceway.
- No overtemperature event occurred for any of the bearings used in the test.

6.0 RECOMMENDATIONS

The following recommendations are made based on the results obtained in this research program:

- Conduct revenue service tests of a prototype HBD system utilizing rail mounted infrared transducers configured to intercept infrared radiation from both the inboard and outboard cup raceways of each bearing.
- Conduct wheel set and bearing inspections on bearings flagged by the prototype HBD system to develop statistical validation data needed to evaluate the premise that wheel sets with grooved journal defects develop measurable thermal gradients across the bearing cup.
- Conduct additional research to evaluate the capabilities and limitations of the current acoustic defective bearing detection technology.
- Conduct laboratory and on-track tests to determine if acoustic techniques can be reliably used to identify the following conditions:
    - Spun cone, grooved journal condition, in the absence of spalling on the rolling contact surfaces, for a bearing operated under loading equivalent to the static empty and fully loaded car conditions.
    - Broken roller element condition in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.
    - Broken cage condition in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR condemnable cone spall defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR non-condemnable cone spall defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR condemnable cup spall defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR non-condemnable cup spall defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR condemnable cup Brinell defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- AAR non-condemnable cup Brinell defect in a bearing operated under loading equivalent to the static empty and fully loaded car conditions.

- Utilize the results of the laboratory and on-track tests to identify, develop, and implement improvements in acoustic signal processing currently in use and improved signal processing techniques.
- In the event that acoustic techniques are unable to detect any of the above defective conditions, develop a plan for investigating alternative strategies or techniques for identifying such defective conditions.

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