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# Roller Bearing System Failure Analysis

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## Summary

There have been significant changes in the roller bearing system, loading and performance monitoring for heavy axle load (HAL) service in the past decade. For example, in reaction to increased axle loads, bearing manufacturers developed the Class K bearing that is designed for better service life under these higher loads. Further changes include improved greases, seals, and plastic cages being used, and more recently, a wider use of advanced truck designs with adapter pads and an introduction of new technology acoustic bearing detector, as a means of maintaining bearings based on performance monitoring.

Recent bearing performance survey results conclude that bearing failure rates vary by car type and bearing class and that implementation of failure progression mode analysis can aid in understanding defect causes.

Under a new Association of American Railroads (AAR) Strategic Research Initiative (SRI) project, the Transportation Technology Center, Inc., (TTCI) Pueblo, Colorado, conducted a survey of six North American Class I railroads to gather bearing failure data from 1999 to 2003 for detailed analysis. The survey portion of this project is intended to define current performance issues related to defect type or failure mode and compare this to the previous survey of hot bearing removals done in 1986 and 1987.

The analysis of this data will ultimately be used to review bearing performance in terms of AAR standards for design, reconditioning, and field detection of defects using all available technologies (including acoustic). Immediate project goals are to determine the effect of changes in the HAL roller bearing environment, to correlate those changes to in-service failures, to determine the means to mitigate failures, and to extend service life and maintenance intervals.

The data collected from the period of 1999 to 2003 consists of 7,551 confirmed hot bearing removals including 235 burned-off journals (bearing failure was defined as a burned off journal or confirmed hot bearing removal), and covered AAR bearing classes D, E, F, G, and K. A new method of assigning failure causes called Failure Progression Modes (FPM) was used in place of the traditional AAR MD-11 codes. The data survey is summarized by car type, bearing size, and car maximum weight.

The AAR Universal Machine Language Equipment Register (UMLER) database was used to assign car type and Gross Rail Load (GRL) information to each defect by car reporting mark. Thus the data could be analyzed by bearing load and type of service. Defect descriptions were generally reported using the AAR MD-11 codes, but newer FPM codes developed by the roller bearing manufacturers are better suited to analyzing root causes and defects found regardless of bearing heat (e.g. found acoustically).

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**INTRODUCTION AND CONCLUSIONS**

In an effort to review overall roller bearing performance under freight equipment in North America, the AAR gathered a database of over 7,500 confirmed hot bearing inspections including over 200 burned-off journals (BOJ) inspections covering the period from 1999 to 2003 from six Class I railroads in the United States and Canada. The last AAR industry review of major bearing failure causes was done during 1986 and 1987 and led to revisions in the bearing reconditioning, mounting, and design standards. This study is intended to review new performance data and compare it to the 630 hot bearing inspections completed around 1987 – of which only 447 were verified as hot bearings, while the current data is all verified.

Initial review shows that the rate of bearing failures varies widely across the North American car fleet and that coal and intermodal cars especially experience a higher than average rate of overheated bearings. The survey indicated that the previous dominant failure mode of loose or spun cones was diminished but is still one of the leading failure causes. Other conclusions are listed below:

- Class E and G bearings experience a higher percentage of failures than their percentage of population.
- About 1/3 of all overheated bearings in the survey experienced a hot box failure during their initial service life, 2/3 after reconditioning cycles.
- Loose cone failure and water etch are the largest causes of failure.
- Failure Progression Modes (FPM) are a new method to look at performance data for both hot box and acoustic detectors and should provide insight into failure causes.

**METHODOLOGY**

Data on confirmed hot bearing inspections was collected in 2004 from the Class I railroads. This included BOJ data, although inspections were generally limited to the mate bearing due to the extent of the failure. The data received was not in a common format, nor was it consistent in content. The car numbers were run through the industry’s Universal Machine Language Equipment Register (UMLER) database to determine car type and gross rail load (GRL) information. The GRL database was then used to analyze bearing performance under HAL equipment (286,000-pounds GRL).

The growth in the volume of HAL traffic since the last performance review in 1987 was one concern that prompted this SRI. In general, an attempt was made to normalize the defect data by appropriate population size (the bearing class, car type, or GRL group population).

**RESULTS**

**General Statistics by Bearing Class**

The bearings in the database are comprised of AAR classes D, E, F, G, and K. The percentage population of each of the classes found through the UMLER database. Table 1 shows the population percentage by size, as well as the confirmed overheated bearings and BOJ by size.

Generally, the Class E and G bearings had a slightly higher percentage of verified overheated bearing or BOJs than their percentage of the population. The Class F and K bearing failures were slightly lower than their percentage of the population. It should be noted that the Class K is a new design and the average bearing age is much younger.

**Table 1. Bearing Defects by Class**

Bearing Class	Population Percentage	Overheated Percentage	BOJ Percentage
D	0.41%	0.24%	0.00%
E	20.38%	27.48%	27.54%
F	75.60%	70.12%	71.61%
G	1.36%	1.83%	0.85%
K	2.07%	0.33%	0.00%

**Original against Reconditioned Equipment**

The overheated bearing data was analyzed for original applications (OEM) compared to bearings that were reconditioned one or more times. Table 2 shows the OEM compared to reconditioned percentages by bearing class and compared to that of similar data from 1987.

**Table 2. OEM by Class. 1997 to 1999 – 2003 Survey**

Bearing Class	OEM Percentage	Reconditioned Percentage	Unknown Percentage
D	16.7%	83.3%	0.0%
E	22.1%	77.6%	0.3%
F	39.0%	60.5%	0.5%
G	15.9%	84.1%	0.0%
K	92.0%	8.0%	0.0%
Total Population 1999-2003	34.0%	65.6%	0.4%
Total Population 1987	32.0%	52.0%	16.0%

It is noted that the OEM population is around 30 percent, which is similar to the previous data from 1987. The older data was not broken down by bearing class. It is also interesting that the Class F bearing in the current data shows a much larger percentage of OEM failures than Class E or G (the only other significant classes for comparison, since the population of D is small and older in age, and K is small and newer in age).

**Bearing Defect Coding**

Most of the bearing performance data as received had the initial defect code and the cause of heat code as dictated by the AAR MD-11 form. In addition, over half the data included the proposed FPM codes as prepared by the Roller Bearing Manufacturers Engineering Committee (RBMEC).

The MD-11 list of defect codes has 52 entries, which requires two codes chosen to define an overheated bearing failure. The first code is defined as the initial defect and the second code as the cause of heat. Some railroads interpret those codes to mean that a bearing with internal defects but no sign of heat is classified as a false set-out. Recent RBMEC evaluations indicated that different individuals will use different code combinations on the same bearing defect about half of the time.

Besides the large number of combinations, the codes tend to indicate symptoms of the bearing defect as seen during inspection, not necessarily as the root cause of bearing performance failure. That is why this analysis mainly uses the FPM system using only 13 codes to classify the cause of failure and to assist in recommendations for performance improvement. In addition, the FPM system can be used for any bearing defect found, irrespective of heat, such as acoustic detector removals.

FPM codes were established for all the confirmed hot bearings in the survey. The percentage results are given in Table 3 by major bearing class. (Classes D and K were omitted because of the small population size.) The FPM categories are described as defects related to the adapter (displaced, worn, broken, or wrong size), application (caused by assembly or installation), bearing destroyed (no cause can be determined), displaced seals (cocked, loose, or displaced), bearing loose (any or all loose components), lubrication (loss of grease or breakdown of grease), manufacturing defect (mixed components, assembly defects, manufacturing defects, or out of tolerance components), mechanical (external abuse such as heat applied, impacts, derailments, electric arc, brinelling, or seals dented), fatigue spalling (material cyclical load fatigue spalling), truck related (uneven loading from truck components), wheel defect (distress caused by tread defects), and water etch (water ingress and raceway etching). The additional category not mentioned is Not Verified, to include detector set outs that reveal no evidence of distress.

**Table 3. FPM Population Percentages by Class**

Bearing Class / FPM	E	F	G	All Classes
Adapter	7.7%	5.2%	1.4%	5.8%
Application	2.1%	1.6%	0.7%	1.7%
Bearing Destroyed	14.5%	11.5%	10.7%	12.3%
Displaced Seal	2.0%	1.9%	2.1%	2.0%
Loose	28.3%	19.7%	12.9%	21.8%
Lubrication	3.0%	2.7%	26.4%	3.3%
Manf'g Defect	0.5%	0.2%	0.7%	0.3%
Mechanical	6.9%	6.5%	9.3%	6.7%
Fatigue Spalling	11.6%	14.2%	5.0%	13.3%
Truck Related	0.1%	1.1%	0.0%	0.8%
Wheel Defect	8.8%	9.8%	28.6%	9.9%
Water Etch	14.5%	25.6%	2.2%	22.1%

**Table 4. 1987 Defect Population Percentages**

Defect	Total	U.S.	Canadian
Spun Cone	46%	52%	18%
Spalling	14%	11%	24%
Broken Cup	3%	4%	3%
Broken Cone	2%	2%	4%
Water Etch	4%	2%	13%
Peeling	2%	2%	4%
Brinell	2%	2%	1%
Other	27%	25%	34%

Table 4 shows a general list of defects determined to be the cause of failure from the study of 1987<sup>1</sup> and a comparison of the recent data (Table 3) with the previous study (Table 4) shows that the large population of spun cone or loose bearings from 1987 was reduced significantly, while water etch rose dramatically.

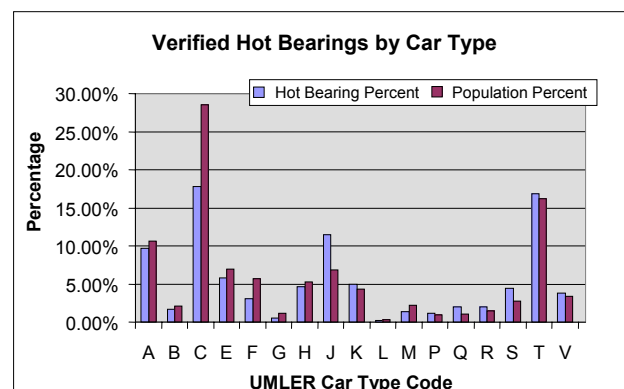
The comparison of broken components from 1987 (about 7 percent for broken and brinell) compares with the Mechanical FPM (6.7 percent). Spalling defects are also almost unchanged (13 percent to 14 percent). The limited categories used in 1987 and wide use of "other" category make more comparisons difficult.

The industry made a concerted effort to attack the loose bearing defect since 1987 and it appears that these efforts were fruitful.

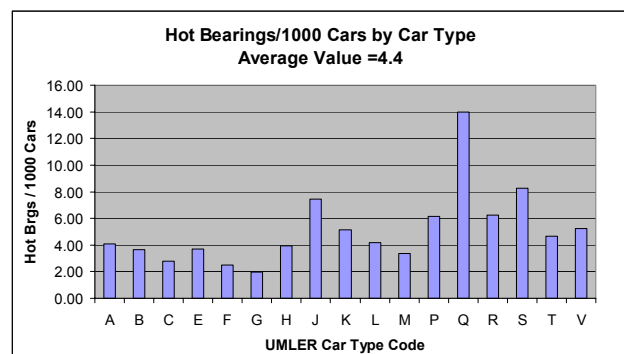
### Bearing Failures by Car Type and GRL

A more detailed look at the verified hot bearing data by car type is shown in Figures 1 and 2. The first figure presents the percentage of hot bearings by car type as well as the population percentage by car type. Figure 2 shows a hot bearing rate (hot bearings per 1,000 cars) by car type. The car type codes are those used in the AAR UMLER database as listed in Table 5.

Together, Figures 1 and 2, show how bearing failures break down by car type. For example, car type C in Figure 1 is the largest single car group (27 percent), but only has 17



**Figure 1. Verified Hot Bearings by Car Type**



**Figure 2. Verified Hot Bearings /1,000 Cars**

Table 5. UMLER Car Type Code Descriptions

Code	Description	Code	Description
A	Equipped Box	L	Special
B	Unequipped Box	M	MOW
C	Covered Hopper	P	Intermodal Flat
E	Equipped Gondola	Q	Low Profile Intermodal Platforms
F	Flat	R	Refrigerated Box
G	Unequipped Gondola	S	Double Stack Intermodal
H	Unequipped Hopper	T	Tank
J	Gondola	V	Vehicular Flat
K	Equipped Hopper		

percent of hot bearings. Reflected in Figure 2, type C has a failure rate of 2.8 hot bearings/1,000 cars –below the average of 4.4 hot bearings for all car types. In contrast, Figure 2 shows car type J has a rate of about 7.5 hot bearings/1,000 cars, above the average reflected in Figure 1 as 11.5 percent of hot bearings, but 7 percent of the car population. Showing higher than average failure rates are coal, refrigerated box car, and intermodal service car types J, K, Q, R, S, and V. Failure rates cover the five year period of the study.

Figure 3 shows the failure rate for the common GRL limits and the bearing classes associated with them. From this figure we can see the performance of the HAL cars in different fleets (coal, intermodal, tank, and covered hopper).

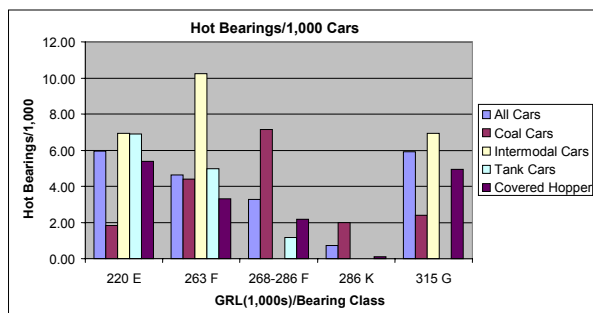


Figure 3. Bearing Failure Rate by GRL/Bearing Class

As shown in Figure 3 the Class E bearing at a car GRL of 220,000 pounds has an average failure rate of 6 hot bearings/1,000 cars, while the F bearing at 263,000 pounds GRL is 4.6 and at 264,000 to 268,000 pounds is 3.3, and the G bearing at 315,000 pounds is 5.9. The figure shows that the E bearing failures are driven by intermodal, tanks and covered hoppers, while the F bearing failures at 263 GRL are driven by coal cars and tank cars. The HAL coal cars drive the higher axle load F bearing failures, while G bearing failures are driven by intermodals (double stacks).

**Discussion**

The roller bearing performance results presented here have just touched the surface of the potential for this survey database to provide insight into the causes of bearing failures

in the North American fleet. Further studies will be done. Although the FPM data shows that loose cones are not the same dominant failure factor as in the past, it is still an important issue. The higher than average failure rate on HAL coal cars and intermodal cars based on population data is important, but must be reviewed based on usage and bearing age. Understanding why failures vary widely by car type and service is needed so improvements can be made. The FPM data, parsed by car type and bearing class will be the method used to ascertain car specific failure modes.

**FUTURE WORK**

The survey database will be used to perform detailed analysis of service specific bearing failures and determine potential mitigation and detection methods and if possible, the data will be normalized by mileage as an additional indicator of service performance. This effort will be initially directed at the HAL environment then expanded to services with bearing performance issues. Finally, acoustic data will be gathered for comparison to hot box detector data using the FPM approach. The goal is to determine the optimal maintenance strategies based on all available detector data which may include wheel impact data based on the observed correlation between high impact wheels and bearing failures.

**CONCLUSIONS**

A survey was conducted and a database prepared based on the hot bearing inspection and BOJ data. The initial summary normalized this data by car type, bearing class, and GRL. The failures were compared where possible to a 1987 study. General conclusions are:

- Class E and G bearings experience a higher percentage of failures than their population.
- About 1/3 of the overheated bearings in the survey experienced a hot box failure during their initial service life, 2/3 after reconditioning cycles.
- Loose cone failure and water etch are the leading causes of failure.
- Coal cars in HAL service have a higher failure rate than most other equipment. Intermodal equipment has higher than average bearing failure rates across all bearing classes.
- FPMs are a new method to look at performance data for both hot box and acoustic detectors and should provide insight into failure causes.

**Acknowledgements**

The authors wish to thank the railroads and bearing manufacturers who worked to provide the data for this study. The 7,000 and more inspections represent a large effort that must be used to benefit the industry in improving bearing performance.

**References**

1. Michael Fec, Journal Roller Bearing Defect Populations, Association of American Railroads, Report Number. WP-146. January 1991.