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NATIONAL TRANSPORTATION SAFETY BOARD
Investigative Hearing
Norfolk Southern Railway general merchandise freight train 32N derailment with subsequent hazardous material release and fires, in East Palestine, Ohio, on February 3, 2023

Agency / Organization

Burlington Northern & University of Nebraska, Lincoln

Title

Exhibit 3- Leedham & Weins, ASME, 1992

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MECHANISTIC ASPECTS OF BEARING BURN-OFF

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ABSTRACT

Bearing burn-off is the most catastrophic mode of bearing failure and results in a small yet significant number of bearing failures in the railroad industry. This paper looks at the factors responsible for bearing burn-off as based on evidence gathered from actual incidents, both in the field and during controlled full-scale testing. The characteristic mechanical and metallurgical damage is reviewed along with explanations for these modes of damage, and discussion on how they contribute to the overall failure sequence. This evidence, combined with thermal data from actual testing involving the initiation of a bearing burn-off, permits formulation of a general model of the event. Results and analysis indicate that the loss of radial and/or longitudinal clamp load are important factors in the initiation of bearing burn-off, and that the integrity of the roller cage is an important factor to the final burn-off event.

INTRODUCTION

Overheated railroad car bearings, also called hot-boxes, are an indication of bearing problems that may lead to catastrophic failure if undetected. Wayside detectors play an important role in maintaining a safe environment for the passage of trains (1). Infrared hot-bearing detectors (HBDs) monitor bearing operating temperatures, checking for overheating, a sign of a bearing's distress and possible catastrophic failure, which could cause a train derailment.

The tapered roller bearing, as shown in Figure 1, introduced a new era to railroading. It was stated: "Hot-boxes will be a thing of the past as all new cars become equipped with roller bearings". However, because of the rapid mode of failure of roller bearings, infrared hot-bearing detectors have not been eliminated; but their numbers have actually increased as HBD spacing intervals have been reduced over the years from 30 to 35 mile (48.3 - 56.3 km) spacing to between 15 and 30 miles (24.1 and 48.3 km).

Failed roller bearings account for several accidents each year on the Burlington Northern Railroad, with damages of several million dollars. Even with nearly 300 infrared hot-bearing detectors installed on Burlington Northern, the number of bearing-related accidents remains fairly steady from year to year. What is needed is a preventative maintenance tool to identify defective roller bearings before their final phase of life.

During 1987, Burlington Northern structured a research program to develop and implement a wayside acoustic bearing detector (ABD). That work involved much testing with bearings containing known defects, including several which resulted in catastrophic failure. The work reported here is a result of that study, and in particular involves two bearings which were tested at the Pueblo Transportation Test Center (TTC). Analysis of these failures indicated that catastrophic heat up and failure (bearing seizure) could occur within 30-60 seconds.

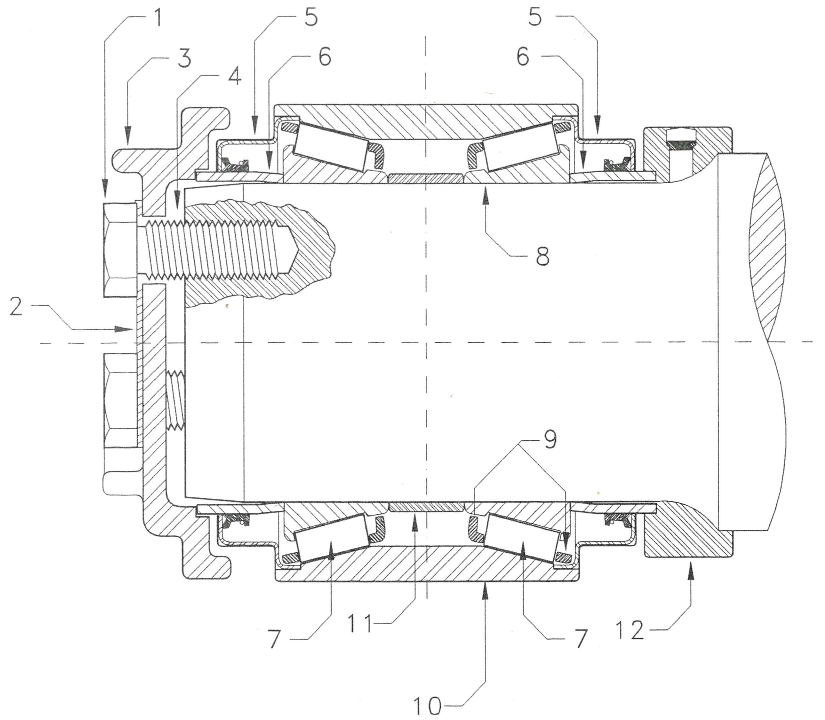
EXPERIMENTAL

EXAMINATION OF FIELD FAILURES

Failure analyses of bearings which have been involved in burn-offs, hot box incidents and field-related problems, can be extremely useful in the determination of the cause(s) for a bearing problem. Whereas bearings from these as well as other histories and stages of failure can provide information on the basic causes of bearing overheating and failure, bearings with well-known histories (mileage, loads and times) which have not been completely destroyed are of most use.

Final Failures.

Each year on Burlington Northern Railroad as well as other railroads, catastrophic roller bearing "burn-offs" occur, resulting in train accidents. Burn-offs usually result in a conical-shaped stub axle on the wheel, as shown in Figure 2, along with the other part of the axle stub and the bearing components which may be fused to various degrees, as shown in Figure 3. The final loss of the bearing and



1. Cap Screws
2. Locking Plate
3. End Cap
4. Cap Screw Seal Rings
5. Seal
6. Seal Wear Rings
7. Roller
8. Cone
9. Cage
10. Cup
11. Spacer
12. Backing Ring

FIGURE 1 SECTION VIEW OF A TAPERED ROLLER BEARING SHOWING LOCATION AND ORIENTATION OF CRITICAL COMPONENTS.

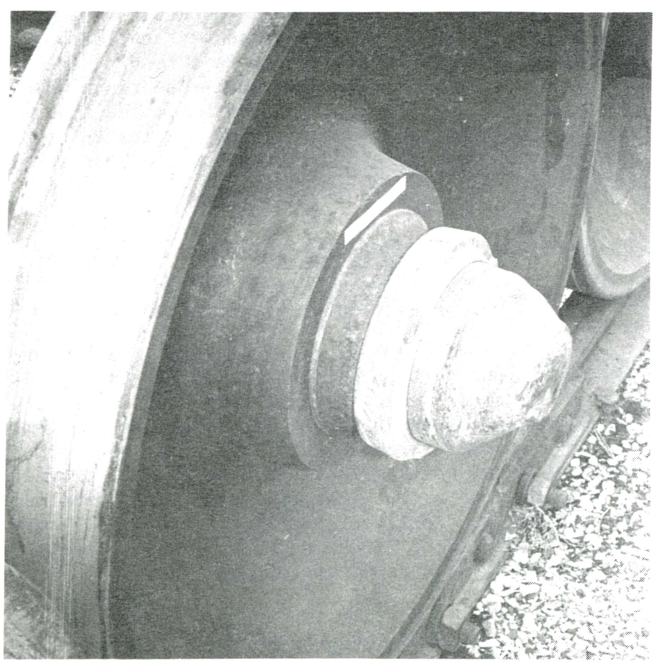


FIGURE 2 TYPICAL APPEARANCE OF BURNED-OFF AXLE.

failure of the axle is always a result of a bending overload failure, due to the fact that in the last phases of burn-off extreme heat has been produced, which along with the rotation of bearing, has necked the axle down in size. The size reduction of the axle, in conjunction with the reduction in yield strength of the steel at elevated temperature, will eventually result in a condition where the axle can no longer support the weight of the car. This is usually evidenced by the fact that the last-to-fail area contains remnants of the final bending event as also shown in Figure 3.

The actual bearing may be a single mass of steel which has been fused together, or it may be separate components consisting of the axle , cup, cones, rollers and spacers, which have been fused to one extent or another. Most often noted is the fact that at least one of the cages is missing, and/or the cage may be deformed to a great extent and is often fused to the rollers. The cup is rarely affected, however, and usually survives in its same basic form. In final failure stages such as these there is of course, no lubricant remaining as it will have been consumed from the heat of the incident.

Evidence from burn-off failures such as these is important, but is often difficult to interpret because of the extreme heat generated by the process, which usually destroys all lubrication and is capable of melting steel. In addition, considerable physical damage is often imparted to the components, and some components may be lost in the derailment process. By careful study and review of the remaining evidence, however, much information on the probable causes of

CONTROLLED TESTING OF DEFECTIVE BEARINGS

General

During December 1987, through May 1988, Burlington Northern Railroad sponsored a series of wayside acoustic bearing tests (3), which were conducted by Transportation Test Center personnel. These tests were performed under direct contract and supervision of Burlington Northern's Research and Development Department.

The test program objective was to evaluate the performance of wayside acoustical detection techniques for identifying defective roller bearings in typical freight cars at normal speeds. These tests were also to serve as a catalyst for the two existing hot bearing detector manufacturers to accelerate development of their production model acoustic detectors. Operating a train with documented defective roller bearings under controlled conditions would allow these two participating organizations to collect data and compare results with known defects, thereby furthering the development of their prototype wayside acoustic detection equipment.

Prior to the testing, most of the bearings were categorized, photographed and documented by the University of Nebraska, working under contract to Burlington Northern Railroad. This work was accomplished at Burlington Northern's Havelock Wheel Shop in Lincoln, Nebraska. The defective bearings were then mounted on axle sets for shipment to TTC where they were placed in the test train consist.

As with all testing at the TTC, safety was a very important factor in the planning and implementation of the tests. Thermocouple probes were mounted on the cups of all defective bearings and monitored for excessive and/or abnormal heat conditions. Two inboard scan HBD's were installed for additional safety on the Transit Test Track (TTT), which is a nine mile oval. Two 70-ton (6 x 11 inch) bearings seized and experienced thermal runaway during the course of this testing. The rapid temperature increase of the bearing cups were detected by the thermocouple probes and monitored inside the instrumentation coach. Neither HBD on the TTT detected either of the thermal runaway conditions. Tear-down inspections were performed on both failed bearings.

Bearing 11-1-L

The first bearing to fail had a loose cone defect. This bearing, which was given identification as 11-1-L, had not been torn down and documented prior to testing, but was selected by "hand rolling" the bearing while on the wheel set in order to determine that at least one cone was apparently loose on the axle. During testing the cup temperature of this bearing rose 230 F in only 37 seconds. This thermal runaway occurred 4.5 miles past one HBD and 6.3 miles past the other. HBD. Figure 5 displays a time history plot of bearing #11-1-L's rapid temperature rise. Figure 6 displays a complete time history plot of bearing #11-1-L which shows not only the rapid temperature rise, but also the rate at which bearing cooled. It took only 20 minutes for the bearing to cool back to ambient temperature. This data demonstrates the reason for so many HBD alarmed bearings going unconfirmed. Train crews, when alerted to a suspect bearing by an HBD, stop the train so a crew member can try to locate the defective bearing. Train crews predominantly use temperature sensitive sticks which melt at prescribed temperatures (200 F on the Burlington Northern) to confirm an overheated bearing. Figure 6 thus demonstrates that under normal conditions, many overheated bearings could cool to a point below which would be confirmed by temperature sensitive sticks. The temperature sticks are a go/no-go indicator. Overheated bearing temperatures must be above the melting point of the stick to confirm that the bearing did not overheat. Infrared non-contact thermometers, alternate devices being tested by train crews on Burlington Northern to confirm overheated bearings do not have this problem.

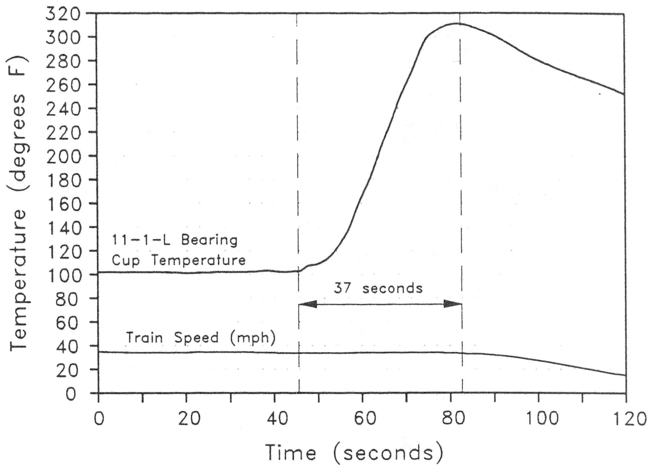


FIGURE 5 THERMAL RUNAWAY OF BEARING 11-1-L.

Bearing 6-3-L

The second bearing to fail had spalled rollers in the outboard cone, and had been identified as #6-3-L. This bearing was inspected and documented prior to the testing. This bearing was "built" at the Burlington Havelock shop by mating reconditioned bearing components and adjusting the lateral and packing with grease according to normal practice. All components in this bearing met reconditioning standards with the exception of the outer cone, which contained severely spalled roller elements. As shown in Figure 7, this bearing exhibited dramatic heating cycles prior to thermal runaway, then increased 290 F in 54 seconds. This bearing failure occurred less than three miles past one HBD and less than five miles past the other HBD.

The thermal runaway of bearings 6-3-L and 11-1-L were similar. Both bearings were located on the right side of the consist, which happened to be the low rail of the TTT for all tests. Thermal runaway for both bearings occurred at 35 mph or less, far below the tracks balance speed of 66 mph. Under these conditions the weight of the car shifted to the low rail, resulting in increased lateral bearing forces. These forces obviously contributed to the seizure of both bearings, within 2 miles of the south curve of the TTT (1.5 degree, 4.5 inch superelevation).

FIGURE 11 TYPICAL APPEARANCE OF ROLLERS FROM OUTBOARD CONE OF BEARING 6-3-L.

FIGURE 12 CUP AND FRONT SEAL OF BEARING 6-3-L.

Other Components. This bearing still contained sufficient grease for lubrication. The front seal was severely scored as a result of the action of the end cap on the seal after lateral fit was lost.

RESULTS AND DISCUSSION

From the evidence examined, and studies cited, it is clear that integrity of the cage/roller assembly is of especial importance to the operation of the roller bearing assembly. In each case cited, in which the bearing was clearly into a thermal runaway condition, one of the cages had deteriorated, causing the roller elements to come loose and jam between the cup and cone. In both cases, this resulted in the rapid generation of heat as evidenced by the thermal plots (Figures 5-7). As also shown, many burn-offs as exampled by Figure 3, appear to have lost at least one cage early in the burn-off sequence.

The loss of the cage in the case of bearing 6-3-L, appears to be related strictly to the condition of the rollers on the cone assembly. This bearing was assembled such that all components met AAR standards except for the outboard cone which contained severely spalled rollers. When the bearing became loaded on this side (outboard), the deteriorated surface of the rollers apparently resulted in excessive wear to the cage. This, combined with the fact that the rollers already had decreased diameters, allowed the rollers to be pushed under the separator bars and/or the separator bars failed as a result of wear and skewed loading. This eventually caused the entire roller set to become free in the bearing. The origin of the outboard cone for this bearing is unknown, and as previously described, all other components and tolerances were within standards. The condition of the rollers in this case, however, were not unlike those which are typically seen in bearings with loose cones, and in fact were in poorer condition than those of bearing 11-1-L. It is highly possible that this cone assembly was originally recovered from a bearing with a loose cone.

The loss of the cage in the case of roller bearing 11-1-L, which contained a loose cone, appears to be the result of a combination of cage wear from the rollers, and a loss of geometry between the axle, cone, roller and cup . The change in bearing geometry

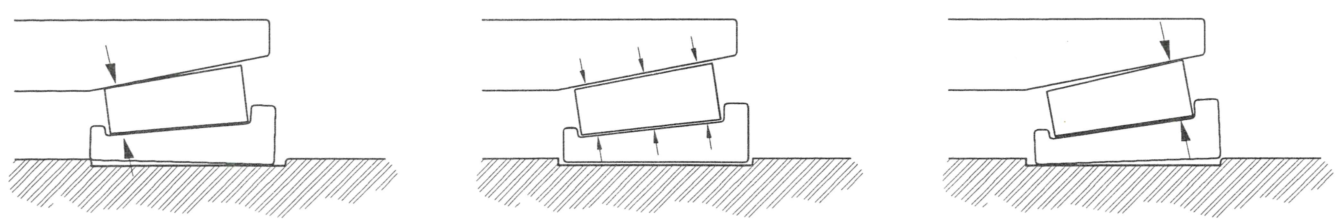


FIGURE 13 CONCENTRATED LOADING OF ROLLERS AS CAUSED BY THE ACTION OF A LOOSE CONE ON GROOVED AXLE.