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EXHIBIT	
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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

American Society of Mechanical Engineers

Title

Exhibit 4- Tarawneh JRC2016, April 2016

(refer to Figure 3). The statistical mean and corresponding uncertainty of the two thermocouples was calculated for every speed and load combination. The uncertainty in the temperature data was within 3°C (5°F). Finally, the data obtained was evaluated according to the defect severity as determined by its area. The approximate area of the spalls was obtained by treating the spall as a rectangle, and measuring the spall's length and width. The area of the spall was measured at the beginning and end of each experiment. The test plan was developed to populate bearing temperature profiles at speeds and loads typical of field service conditions.

RESULTS AND DISCUSSION

The main objective of this study is to compare the temperature profiles of bearings with inner and outer ring defects to those of healthy bearings. In doing so, the effectiveness of temperature monitoring as a tool to assess bearing health is evaluated. The mean ambient temperature in all the experiments performed for this study was approximately 78°F (26°C). The average operating temperatures (above ambient) of bearings with inner and outer ring defects at various speeds for 17% (empty railcar) and 100% (fully-loaded railcar) load conditions are plotted in Figure 4 and Figure 5, respectively, as compared to the average operating temperatures (linear fits with R^2 values of 0.95 and 0.99, respectively) of the healthy (control) bearings at the corresponding speed and load conditions. The average inner ring defect size for the data provided in Figure 4 is 0.77 in^2 (497 mm^2), whereas, the average outer ring defect size for the data given in Figure 5 is 0.92 in^2 (594 mm^2).

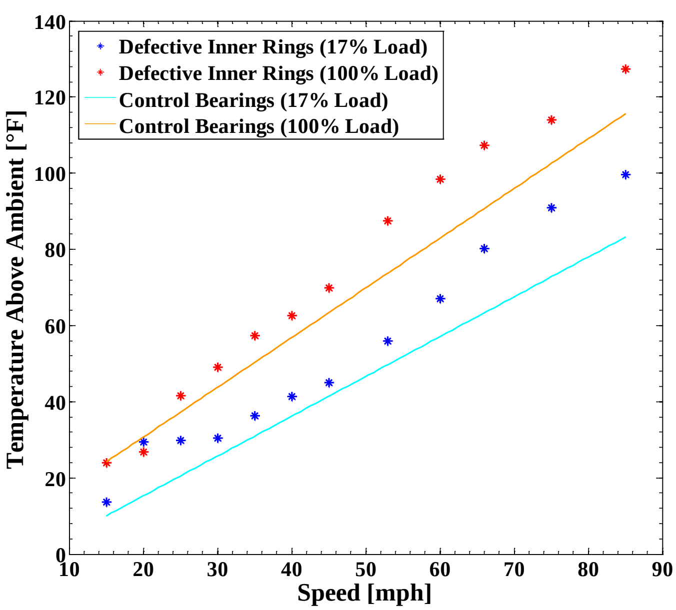

Figure 4. Average operating temperatures above ambient (78°F) of bearings with inner ring defects as compared to healthy (control) bearings at various speeds under 17% (empty railcar) and 100% (full railcar) load conditions.

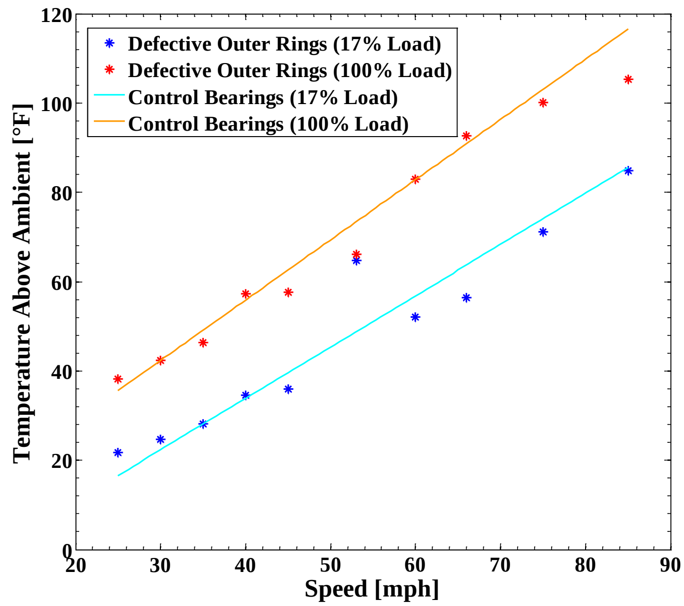

Figure 5. Average operating temperatures above ambient (78°F) of bearings with outer ring defects as compared to healthy (control) bearings at various speeds under 17% (empty railcar) and 100% (full railcar) load conditions.

From Figure 4 and Figure 5, it is evident that there is an almost linear increase in bearing operating temperature with speed. Moreover, speed seems to play a more important role on the bearing operating temperature than load. For example, going from 17% to 100% load will result in an average temperature increase of about 23°F (13°C) in a healthy bearing, whereas, going from 25 to 66 mph results in an average temperature increase of about 48°F (27°C) in a healthy bearing. Note that changes in speed will be more common in field service operation than changes in load.

In Figure 4, the average operating temperatures of the bearings with inner ring defects are mostly above the control bearings average temperature (linear fit). As speed increases, the average temperature of the bearings with inner ring defects appears to diverge from the linear fit of the control bearings; a behavior that is more pronounced in the 17% (empty railcar) load condition. On the other hand, the average operating temperatures of bearings with outer ring defects are consistently at or below the average operating temperatures of the control (healthy) bearings (linear fit) for both loading conditions, as seen in Figure 5. This difference in temperature behavior with respect to the defective bearing component can be explained by referring to the findings in the literature. It was stated earlier that the highest contact pressure during bearing operation occurs between the rollers and the inner ring (cone), and that the higher temperatures within the bearing assembly are seen at the rib – roller contact [8]. It is then expected that if a defect is present on the inner ring (cone) race, it will experience more contact with the rollers, thus, increasing the frictional heating. Moreover, the inner ring is in constant rotational motion, hence, the likelihood of roller misalignment due to contact with the defect is much higher. If roller misalignment occurs, frictional heating is further exacerbated. The combination of the aforementioned effects tends to raise the overall bearing operating temperature which in turn decreases the viscosity of the lubricant leading to more metal-to-metal contact and added frictional heating. The latter becomes even more evident at higher operating speeds (≥ 60 mph), as demonstrated in Figure 4, where the average operating temperature of bearings with inner ring defects is about 15°F (8°C) above that of healthy bearings. One explanation as to why the behavior seen in bearings with inner ring (cone) defects is not observed in bearings with defects present on the outer ring (cup) raceways is that spalls present on the cup raceways may favor the formation of pockets of lubricant which in turn enhances lubrication and maintains the operating temperature at or below the average operating temperature of healthy bearings.

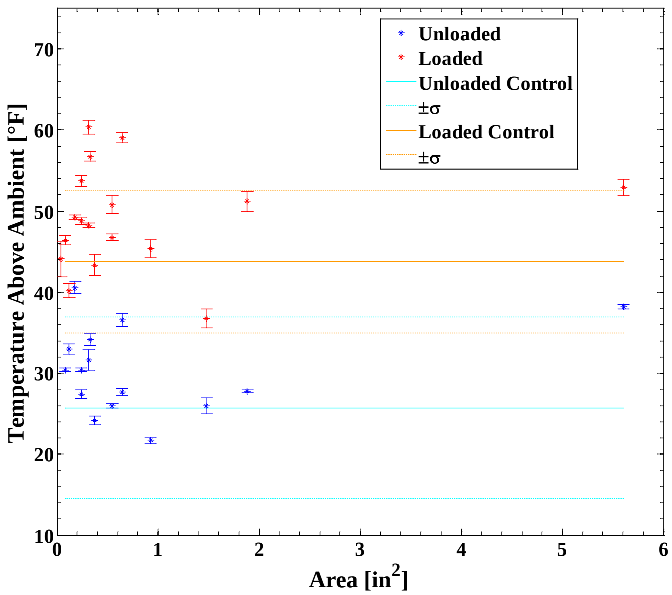

Figure 6. Temperature data of bearings with inner ring defects of various sizes (as measured by defect area) compared against the range of operating temperatures for healthy (control) bearings for unloaded (17% load) and loaded (100% load) conditions at a speed of 30 mph.

For a more detailed analysis, the temperatures obtained for bearings with different size inner and outer ring defects (as measured by the defect area) at two common operating speeds (30 and 60 mph) were plotted and compared against the range of healthy (control) bearing temperatures subjected to the same load and speed conditions. The temperature data for bearings with inner ring defects at operating speeds of 30 and 60 mph are given in Figure 6 and Figure 7, respectively, whereas, the temperature data for bearings with outer ring defects at operating speeds of 30 and 60 mph are provided in Figure 8 and Figure 9, respectively. Note that the data points plotted in Figure 4 and Figure 5 at 30 and 60 mph for the unloaded (17% load) and loaded (100% load) conditions represent an average of all the data points seen in Figure 6 through Figure 9 for bearings with inner and outer defects of various sizes (as measured by the defect area).

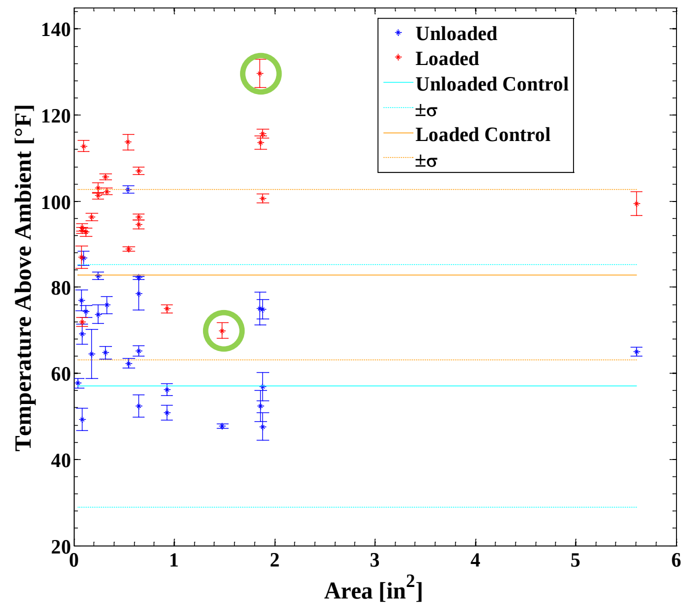

Figure 7. Temperature data of bearings with inner ring defects of various sizes (as measured by defect area) compared against the range of operating temperatures for healthy (control) bearings for unloaded (17% load) and loaded (100% load) conditions at a speed of 60 mph.

By looking at Figure 6 through Figure 9, it becomes apparent that there is no distinct correlation between defect severity and the corresponding bearing operating temperature. While a few bearings with defective inner and outer rings were found to be operating at temperatures above the control (healthy) bearing temperature range for the given speeds and loads, a significant number of bearings with defective inner and outer rings were running at temperatures within or below the healthy bearing temperature range. Therefore, temperature alone does not seem to be a good indicator of the presence of a defect within a bearing, much less of defect severity. The aforementioned statement can be validated by looking at the two data points circled in green in Figure 7. One data point belongs to a bearing with an inner ring defect size of 1.48 in^2 (955 mm^2), whereas, the other data point belongs to a bearing with an inner ring defect size of 1.88 in^2 (1213 mm^2). These two defects are pictured in Figure 10. While the bearing with larger defect size has an operating temperature that is relatively higher than the healthy bearing operating temperature range, the bearing with the slightly smaller defect has an operating temperature that is markedly lower than the operating temperature range for healthy bearings. In fact, the bearing with the inner ring defect size of 1.48 in^2 has an operating temperature that is significantly lower than that of other

CONCLUSIONS

Conventional wayside bearing condition monitoring systems (i.e., Hot-Box Detectors - HBDs) rely heavily on temperature as the main indicator of bearing health. The major drawbacks of the current methods stem from their discrete nature, limited accuracy, and restricted scope—factors that render these systems insufficient to adequately monitor bearing health and effectively detect faulty bearings. In addition to the HBDs, acoustic measuring devices known as the Trackside Acoustic Detection System (TADS®) have been used in the field to identify defective bearings. The success rate of capturing a defective bearing is heavily based on the severity of the defect. Bearings with large defects, known as "growlers", have a much higher rate of being recognized as opposed to bearings with smaller defects. Although nearly five thousand HBDs are currently in service, only fifteen TADS® have been implemented in North America [10], which means a train can run thousands of miles before encountering an acoustic bearing detector. Furthermore, the majority of warm trended bearings are found to be defect-free (i.e., non-verified bearings), which results in waste of resources, both in finances and manpower.

This paper evaluates the operating temperatures of bearings with inner (cone) and outer (cup) ring defects from 70 experiments as compared to the operating temperature range of healthy bearings. No distinct correlations were found between defect severity, as measured by the defect area, and operating temperatures of bearings with inner and outer ring defects. The results of this study demonstrate that a large number of bearings with inner and outer ring defects of considerable size were operating at or below the temperature range of healthy (defect-free) bearings. This finding is of particular concern because it suggests that many defective bearings can go undetected with the current utilized practice of averaging all bearing temperatures on the same side of the train and focusing on those bearings that are operating at temperatures relatively higher than this average. Moreover, none of the defective bearings tested in the experiments performed for this study reached the HBD alarm temperature threshold of 94.4°C (170°F) above ambient conditions set by the AAR.

The findings of this study, in combination with the costly removal of a relatively large number of *non-verified* bearings from service, demonstrate that the current wayside detection methods of bearing condition monitoring are inadequate, as they tend to rely mainly on temperature data which does not seem to provide a clear distinction between faulty and healthy bearings. Onboard condition monitoring systems that are capable of simultaneously tracking the temperature and vibration signatures of each bearing in the train can prove to be much more effective in assessing bearing health.

Future work includes testing bearings with larger size inner and outer ring defects to add to the library of temperature data that has already been accumulated. Additional work, currently in progress, is focused on studying the effects of spall geometry and location on the bearing operating temperature.

ACKNOWLEDGMENTS

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