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Defect detection system for freight railcar tapered-roller bearings using vibration techniques

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Introduction (300 words)

Currently, the wayside hot-box detector is the most utilized bearing condition monitoring system used by the railroad industry with over 5,000 in operation. The hot-box detector uses a non-contact infrared sensor to determine the temperature of the train bearings and other components as they roll over the detector. These temperature measurements are used to determine the condition of the components. Bearings operating at temperatures that are 94.4°C (170°F) above ambient or 52.8°C (95°F) above the mate bearing on the same axle are considered defective, and will trigger an alarm calling for the train to be stopped immediately. Bearings operating at temperatures consistently higher than the average temperature of all the bearings on the same side of the train as detected by multiple hot-box detectors are classified as “warm-trended” bearings. “Warm-trended” bearings do not trigger the hot-box detector alarms but are removed from service as a precautionary measure to be disassembled and inspected. The issue with these wayside temperature-based condition monitoring systems is the measured temperature can be significantly different from the actual operating temperature of the bearing due to several external factors such as the class of railroad bearing and its position on the axle relative to the position of the wayside detector. Over the past two decades, current wayside detection systems have failed to identify a few severely defective bearings, some of which have led to costly catastrophic derailments. In an attempt to optimize the current bearing condition monitoring systems, certain railroads have developed stricter temperature thresholds. These stricter thresholds have led to a significant increase in the number of defect-free, or “non-verified”, bearings removed from service, and have resulted in costly delays and inefficiencies. In fact, according to data collected by Amsted Rail, Inc., approximately 40% of bearings removed from service based on hot-box detector readings were non-verified.

Methods (300 words)

A vibration-based condition monitoring system has been developed that can accurately identify defective bearings at a very early stage allowing for proactive maintenance to be performed. Two vibration thresholds were devised to determine the condition of the bearing: a preliminary threshold and a maximum threshold. The preliminary threshold was identified first by determining the average acceleration for numerous bearings operating at various speeds and loading conditions, and then using statistical analysis to generate a correlation that contains the least number of defect-free and the highest number of defective bearings over the correlation. The maximum threshold was established so that 100% of all bearings with accelerations above it would be defective.

Once the acceleration of a bearing exceeds the maximum threshold, the onboard monitoring system will then determine the defective bearing component utilizing frequency-domain analysis, which consists of tracking rotational frequencies in a power spectral density (PSD) plot. The PSD plots for bearings containing different defective components and defect-free bearings have unique characteristics. These characteristics can be quantified by calculating six fundamental bearing frequencies: three fundamental rolling bearing frequencies and three fundamental defect frequencies. The fundamental rolling bearing frequencies are based on the rotational speed and measurements of the tapered-roller bearing specified in the manufacturer drawings, whereas, the fundamental defect frequencies are based on the presence of defects or geometric inconsistences on the rolling elements of the bearing. Due to the uniqueness of each frequency spectrum, the defective component within a bearing can be identified by calculating the normalized defect energy (NDE) for each defect type and determining which of the three NDEs is greater. Normalized defect energy refers to the summated areas under a specified defect frequency and its harmonics within the PSD, divided by the total number of harmonics within a defined frequency range. To determine the defective component present within the identified defective bearing, the highest normalized defect energy of the three defect types must be greater than or equal to 50% of the sum of all three normalized defect energies.

Results (300 words)

Two dynamic bearing testers were used to perform all relevant experiments for this study: a single bearing test rig, and a four bearing test rig. Four accelerometers are used on both test rigs: two per bearing adapter on the four bearing test rig, and four on the bearing adapter for the single bearing test rig. Bearing operating temperatures are tracked and recorded utilizing one K-type thermocouple wedged in between each bearing and adapter as well as two bayonet K-type thermocouples per bearing adapter. One of the performed experiments (Experiment 203) employed a bearing with a defective outer ring (cup) having a spall on the outboard side of approximately 0.865 cm^2 (0.134 in^2), shown in Figure 1, placed in the bearing 3 position on the four bearing tester. The spall propagated throughout the course of the experiment growing to a size of 9.50 cm^2 (1.4725 in^2). Bearing 2 is a control (healthy) bearing used as a comparison between a defective and a healthy bearing.

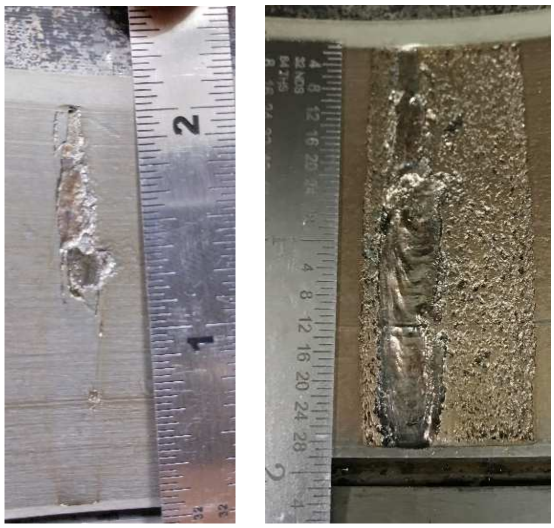
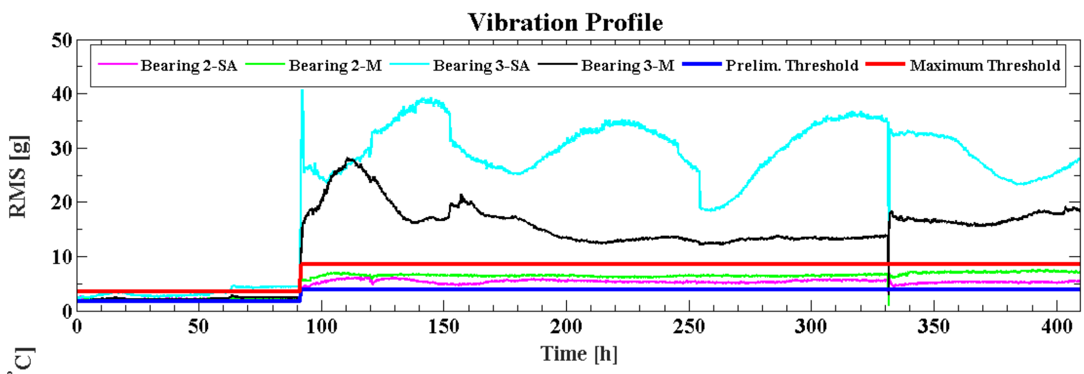


Figure 1. Initial cup spall for bearing 2 (left); deteriorated cup spall for bearing 2 (right)



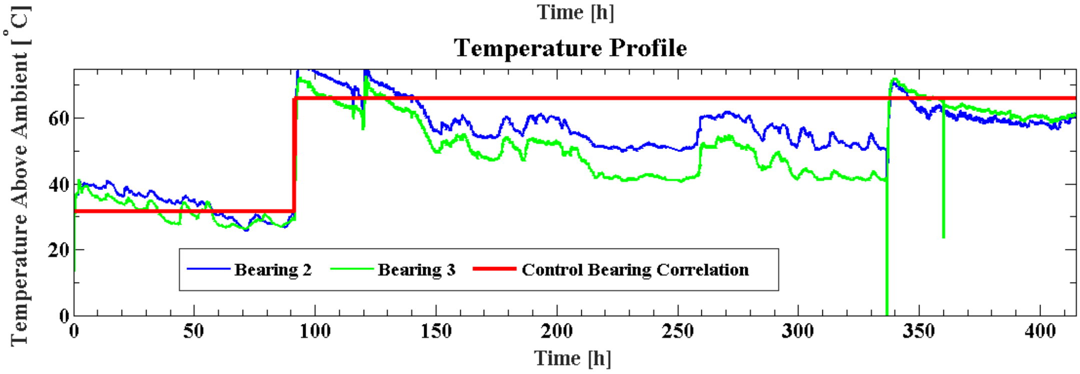


Figure 2. Vibration and temperature profiles for Experiment 203

Table 1. Average values for Experiment 203 for Bearing 2 and Bearing 3

Bearing 2 (Healthy)								
Speed [mph]	Load [%]	ΔT [°C / °F]	Control ΔT [°C / °F]	RMS [g]	Prelim. Threshold [g]	Max. Threshold [g]	Defect Type Detected	Confidence [%]
40	100	31.7/57.1	31.4/56.5	2.1	1.7	3.4	N/A	N/A
85	110	55.5/99.9	66.0/118.8	6	3.8	8.5	N/A	N/A
Bearing 3 (Defective)								
Speed [mph]	Load [%]	ΔT [°C / °F]	Control ΔT [°C / °F]	RMS [g]	Prelim. Threshold [g]	Max. Threshold [g]	Defect Type Detected	Confidence [%]
40	100	29.7/53.5	31.4/56.5	2.8	1.7	3.4	Cup	98
85	110	51.5/92.7	66.0/118.8	22.9	3.8	8.5	Cup	97

The vibration and temperature profiles for Experiment 203 are shown in Figure 2 and Table 1. Bearings 2 and 3 operated at similar temperatures throughout the experiment, however, bearing 2 (healthy) operated at consistently higher temperatures than bearing 3 (defective). The opposite is true when looking at the vibration profiles. At higher speeds, bearing 3 operates at almost four times the vibration levels of bearing 2. Since bearing 3 operates with vibration levels above the maximum threshold, the defect type was correctly calculated with a 97.5% confidence level. The oscillations in the vibration levels of bearing 3 are caused by the spall growing in size during testing, as opposed to the steady vibration levels experienced by the healthy bearing 2. Similar results have been produced by bearings with defective components as small as 0.735 cm^2 (0.114 in^2).

Conclusions and Contributions (300 words)

Current wayside condition monitoring systems are reactive in that they normally detect defective bearings towards the end of their lives, which does not allow for preventative maintenance cycles. Hot-box detectors are not effective in identifying defective bearings because temperature measurements alone are not a reliable metric for determining bearing health. Not only have hot-box detectors failed to recognize defective bearings that have led to derailments, but almost 40% of the flagged bearings were found to be defect-free. Hence, a new vibration-based technique has been developed and field-tested that can accurately and reliably identify defective bearings in service.

Utilizing both, accelerometers and thermocouples, an onboard condition monitoring system capable of tracking the health of railroad bearings in service was developed. Two vibration thresholds were identified to track the bearing condition throughout its operating service life. The system can also determine the defective component without the need to disassemble and inspect the bearing. This new system can accurately and reliably identify bearing defects as small as 0.735 cm^2 (0.114 in^2) and track the defects as they deteriorate. Current efforts are focusing on developing correlations to estimate the defect size from the vibration levels. This

information will be used in conjunction with other work involving tracking defect growth in relation to distance travelled, which will allow railroads to plan efficient and proactive maintenance schedules that will greatly reduce costly and unnecessary train stoppages and delays. The latter will also prevent severe damages to rail infrastructure that can result from an undetected defective bearing catastrophically failing and causing a derailment.

Keywords: Vibration-Based Technique, Condition Monitoring, Defect Detection, Bearing Health Metrics